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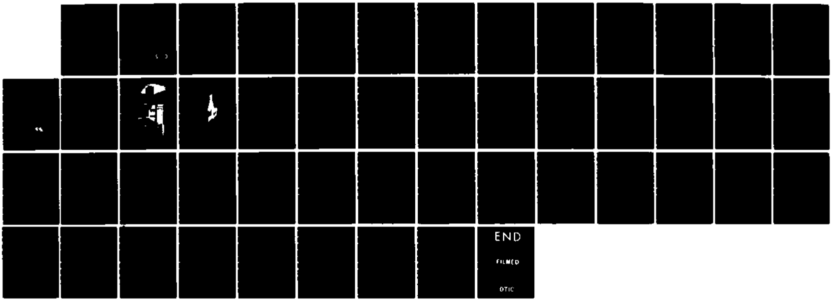

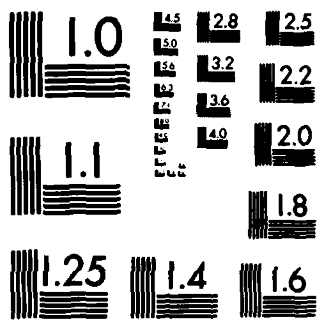
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Preliminary Evaluation of an Improved Flammability Test Method for Aircraft Materials

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December 1984

Final Report

US Department of Transportation
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16. Abstract

Small-scale flammability test methods were evaluated by comparing data obtained on a series of interior honey-comb panels with fire test results obtained with a 1/4-scale cabin model.

Generally, the vertical Bunsen burner, limiting oxygen index and radiant panel test methods ranked the phenolic-faced panels higher (better performance) than the epoxy-faced panels. It appears as if these test methods, which employ relatively moderate exposure conditions, are reflecting the superior ignition resistance of the phenolics over the epoxies. Thus, these tests cannot predict the performance of materials that exhibit high burning rates when subjected to heating conditions above their ignition threshold. The heating conditions used in the Ohio State University (OSU) apparatus, however, can be set at higher levels. At 5 watts/cm^2, rank ordering materials based on peak heat release rate measured via oxygen depletion in the OSU apparatus agreed with materials ranking in the 1/4-scale model. Based on the scope of this investigation, the OSU apparatus operated at these conditions and employing oxygen depletion calorimetry is the recommended improved fire test method for interior panels.

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EXECUTIVE SUMMARY

During an intense postcrash cabin fire, the hazards produced by burning interior materials may prevent the safe evacuation of airplane occupants. Current Federal Aviation Administration (FAA) flammability regulations specify material acceptability limits using a Bunsen burner test method. It has been demonstrated that the Bunsen burner test does not reflect the conditions or predict the performance of a material in a major cabin fire. FAA is evaluating several candidate improved fire test methods, primarily on the basis of degree of correlation with large-scale cabin fire tests. This study is a preliminary evaluation based on comparisons with 1/4-scale cabin model test results.

The basic approach was to test five types of interior honeycomb panels in the model as well as in candidate small-scale tests, and to compare the data. The difference between the types of panels tested was in the composition of the facings; two resins were used, epoxy and phenolic, and three cloths, fiberglass, Kevlar™ and graphite. The panel designs represent a variety of state-of-the-art compositions.

In the 1/4-scale model, the phenolic/fiberglass panel exhibited superior flammability performance than the epoxy/fiberglass panel. This finding was reassuring since the trend in cabin interior design has been to replace epoxy/fiberglass with phenolic/fiberglass. Also, model test results indicated that the fire performance of the phenolic/graphite panel was superior to the phenolic/Kevlar panel. This finding was significant because replacement of fiberglass with graphite or Kevlar cloth results in weight saving advantages.

Evaluation of the small-scale test methods primarily consisted of comparing the rank ordering of materials deduced from small-scale and model test data. Generally, the vertical Bunsen burner, limiting oxygen index and radiant panel test methods ranked the phenolic-faced panels higher (better performance) than the epoxy-faced panels. It appears as if these test methods, which employ relatively moderate exposure conditions, are reflecting the superior ignition resistance of the phenolics over the epoxies. Thus, these tests cannot predict the performance of materials that exhibit high burning rates when subjected to heating conditions above their ignition threshold. The heating conditions used in the Ohio State University (OSU) apparatus, however, can be set at higher levels. At 5 watts/cm^2, rank ordering materials based on peak heat release rate measured via oxygen depletion in the OSU apparatus agreed with materials ranking in the 1/4-scale model. Based on the scope of this investigation, the OSU apparatus operated at these conditions and employing oxygen depletion calorimetry is the recommended improved fire test method for interior panels.

INTRODUCTION

OBJECTIVE.

The objective of this study was to determine the correlation between fire test results obtained in a 1/4-scale model and data obtained from standardized, small-scale, flammability test methods. Secondary objectives included (1) comparing heat release rate data from three types of small-scale, test methodologies, and (2) analyzing fire test results from developmental, small-scale, flame-spread test methods.

BACKGROUND.

The flammability of cabin interior materials used in commercial transport aircraft are governed by regulations issued by the Federal Aviation Administration (FAA). Currently, under Federal Aviation Regulation (FAR) 25.853, except for an insignificant quantity of small parts, all interior materials must be "self-extinguishing" in a vertical orientation when subjected to a Bunsen burner flame along the bottom edge (reference 1). It is generally accepted that this vertical Bunsen burner test addresses the ignitability of a material exposed to a small ignition source; e.g., a condition that might accidentally occur while the aircraft is in flight. Over the past 20 years, for United States (U.S.) air carriers, there has not been a fatal in-flight fire originating in an accessible area of a passenger airplane. Undoubtedly, the "self-extinguishing" requirements embodied in FAR 25.853 have contributed to this excellent record. The small number of fire fatalities which do occur in accidents involving U.S. air carriers are the result of postcrash fires, which are often initiated by a large pool of burning aviation Kerosene (reference 2). Obviously, the Bunsen burner test does not reflect the intense fire conditions and various hazards present during a postcrash cabin fire.

The main thrust of the present FAA Cabin Fire Safety Program is to develop more reliable improved small-scale fire test methods for aircraft materials (reference 3). In recent years, improved fire test methods have been developed for evacuation slides (reference 4), cargo liners (reference 5), and seat cushions (reference 6). For each of these devices, the major goal of the test method development was to demonstrate a correlation with realistic, full-scale test results. Relatively straight-forward criteria were initially apparent for both slides and cargo liners, and this was ultimately incorporated into the test procedure. These end points for slides and cargo liners were inflation pressure retention and burn-through, respectively. However, for seat cushions and other cabin interior materials, the ultimate measurement criteria is usually occupant survivability, which is significantly more complex because it depends on many variables.

Cabin fire hazards affecting survivability are; flammability, smoke, and toxicity. The relative importance of each of these hazards will depend upon the circumstances surrounding any particular accident. For a postcrash cabin fire, which is the primary concern of the present FAA program, a large pool fire is the most predominant type of ignition source. During full-scale, postcrash cabin fire tests initiated by a large pool fire, it was determined that flashover had the greatest bearing on occupant survivability (reference 7). Flashover, as defined here, is the sudden and rapid uncontrolled growth of the fire from an area in the immediate vicinity of the ignition source to the remainder of the cabin interior. Before the onset of flashover, heat, smoke and toxic gas levels were clearly tolerable; after

the onset of flashover, all hazards increased rapidly to levels that would have made survival very unlikely. Thus, the most effective and direct means of minimizing the hazards of burning cabin materials - for an intense postcrash fire - is to delay the onset of flashover. Flammability considerations in contrast to smoke and toxicity directly effect the occurrence of flashover. Therefore, an appropriate flammability test method is the best approach for testing and evaluating materials for the purpose of minimizing their hazards during a postcrash cabin fire.

Since the issuance of a proposed FAA regulation for seat cushion flammability (reference 8), the main emphasis of the Cabin Fire Safety Program has been to establish an improved flammability test method for the cabin interior panels used in the construction of sidewalls, stowage bins, ceilings, and partitions. From a fire safety viewpoint, panels are important because of their large surface area potentially being involved in a cabin fire. The final selection of an improved fire test method for interior panels will be dictated by the degree of correlation with full-scale test results. As a preliminary analysis, this study compares panel test data obtained from a number of promising standardized and developmental flammability test methods with panel test data obtained in a 1/4-scale cabin model. At this time a reduced scale model (e.g., 1/4-scale) probably represents the best indication of full-scale behavior of any small-scale test method (reference 9).

DISCUSSION

DESCRIPTION OF TEST MODEL.

The test model represented a 1/4-scale model of an aircraft cabin whose dimensions were 16 feet wide, 24 feet long and 8 feet high. Thus, the respective model dimensions were 4 feet, 6 feet, and 2 feet. This model had a 1-square foot opening in the front as a door. The box was framed out using 1/8 inch mild steel reinforced at the edges with 3/4-inch angle iron. The interior walls of the box were lined with a 1 inch thick Kaowool™ board. The area lined included the floor and 24 inches up from the floor. The ceiling test panel rested on the 1-inch ledge created by the Kaowool board. A 2-inch gap existed between the test panel and the roof of the model which was also lined with Kaowool. The roof served as a cover for the model box and was secured to the box with clamps to minimize any leakage through the roof (see figure 1).

The fire source was a gas burner with a 10-inch square surface area and fed by propane at a flow rate of 4350 milliliters per minute, producing a calculated heat release rate of 263 British Thermal Units per minute (Btu/min).

This gas burner resulted in a heat flux to the ceiling over the fire measured at approximately 4 Btu/ft^2-sec. Propane was selected as the fuel source due to its high radiant heat output caused by the relatively large amount of soot produced by the propane flame. The burner pan size and flow rate were experimentally varied to match the temperature and heat flux profiles obtained in a prototype model, which used an open fuel pan fire containing JP-4 jet fuel. The flow was adjusted so the top of the plume reached the bottom of the ceiling panel. The ignition source was an electric spark (see figure 1)

The ventilation was natural (no fans were used) and controlled by the fire and the pressure differential between the inside of the box and the outside environment at the door.

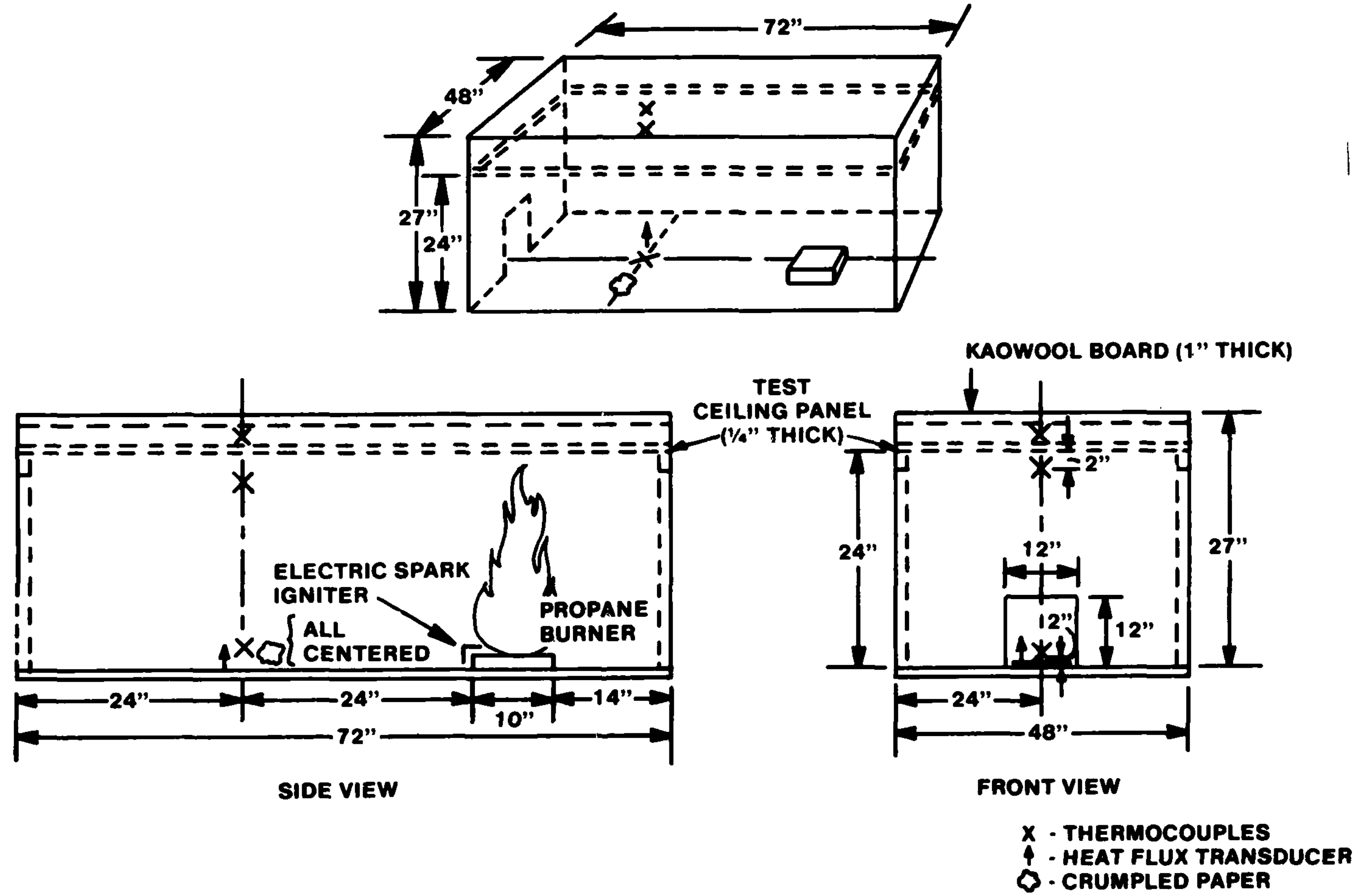

FIGURE 1. ONE-FOURTH SCALE MODEL

Data collection involved quantitative instrumentation as well as visual observations. The quantitative instrumentation included the use of a Hycal Model 1000-1 calorimeter, mounted on the floor facing upwards and located 2 feet from the fire toward the front of the model. The calorimeter was used to measure the incident heat flux from the ceiling and smoke layer. A thermocouple tree was placed at a distance of 2 feet from the fire. The tree was instrumented with two thermocouples used to measure the temperature at 2 inches below the ceiling panel and 2 inches above the floor. A single thermocouple was placed between the test panel and the model roof to assist in evaluating the insulating characteristics of the test panel (see figure 1).

The visual observations included use of a crumpled newspaper placed 2 feet from the fire in line with the calorimeter and the thermocouple tree. The ignition of the paper was indicative of the total heat flux at the floor level of the model. In addition, visual coverage was provided by the use of a black and white video camera viewing the fire through the front door. Qualitative observations of fire plume behavior and smoke obscuration were recorded.

DESCRIPTION OF STANDARDIZED SMALL-SCALE TEST METHODS.

Vertical Bunsen Burner - This laboratory test is American Society for Testing and Materials (ASTM) standard test method for aerospace materials response to flame, with vertical test specimen (for aerospace vehicles standard conditions) (designation: F501-77). It is used for showing compliance with FAR 25.853. This apparatus consists of a draft-free cabinet, 14 by 14 by 30 inches high, a specimen holder, a Bunsen burner with the necessary equipment to meter and regulate gas flow, and a timer for recording the flame times (figure 2). Per FAR 25.853, fabrics, foams, and carpets are exposed to the Bunsen burner flame for 12 seconds, while thermoplastics and panels are exposed for 60 seconds. The flaming time (time in seconds that the test specimen continued to burn after removal of the burner flame) and burn length (the distance from the exposed edge of the test specimen to the farthest evidence of irreparable damage, not including damage from soot or smoke) are recorded.

Limiting Oxygen Index - This laboratory test is ASTM standard test method for measuring the minimum oxygen concentration to support candle-like combustion of plastics (oxygen index) (designation: D2863-77). It provides a means for comparing the relative flammability of physically self-supporting materials. The minimum concentration of oxygen in a slowly rising mixture of oxygen and nitrogen that will barely support combustion is measured under equilibrium conditions of candle-like burning. The balance between the heat from the combustion of the specimen and the heat lost to the surroundings established the equilibrium. This point is approached from both sides of the critical oxygen concentration in order to establish the oxygen index.

The apparatus consists of a test column of a heat-resistant glass tube (3 inches inside diameter and 17.75 inches high) as shown in figure 3. At the base of the column is a bed of glass beads approximately 3 inches deep to mix and distribute the metered mixture of oxygen and nitrogen evenly. The limiting oxygen index (LOI) is the minimum concentration of oxygen, expressed as percent by volume, in a mixture of oxygen and nitrogen which will barely support combustion of a material using an ignition source consisting of a tube with a propane gas flame.

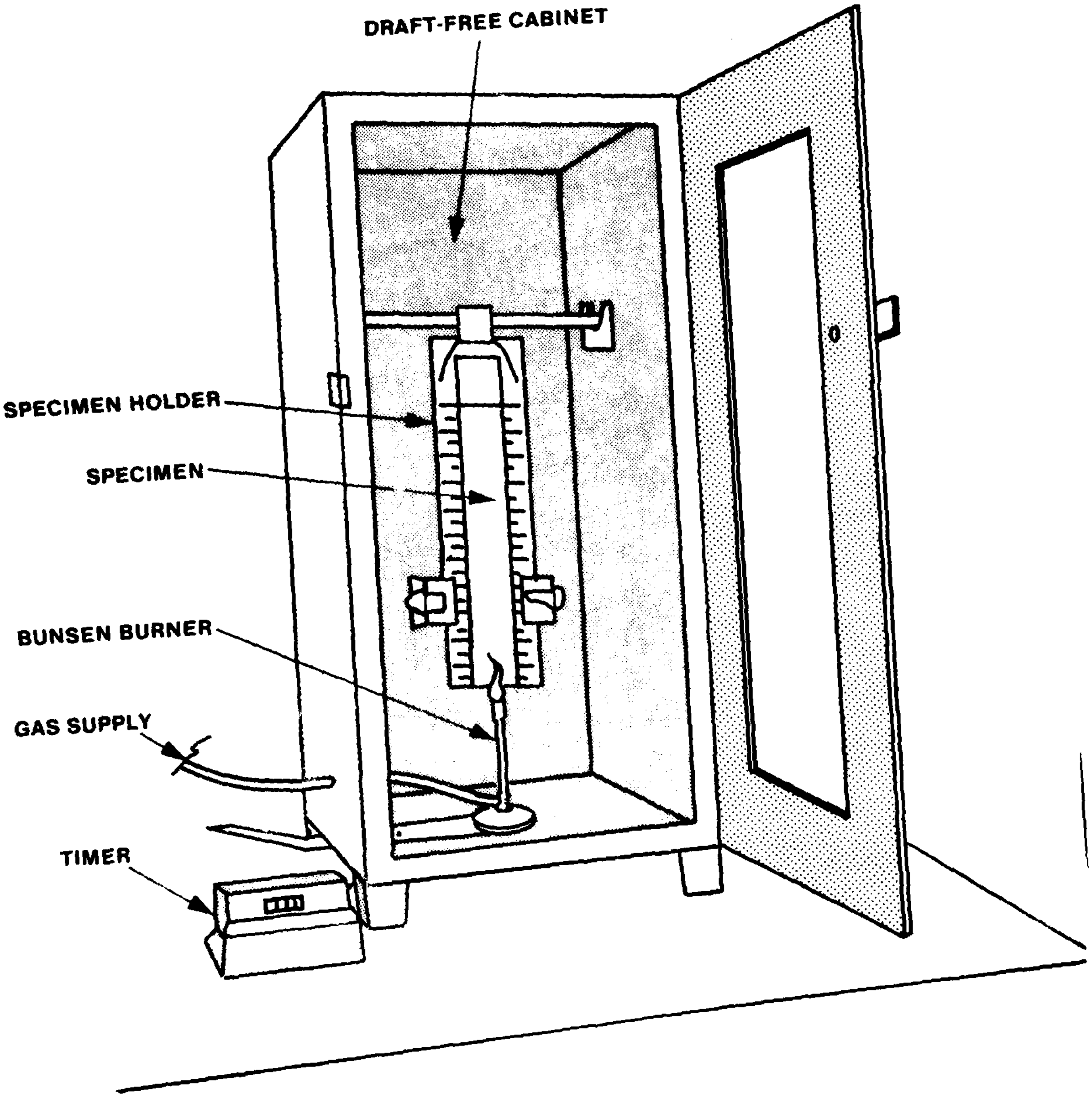

FIGURE 2. VERTICAL BUNSEN BURNER TEST METHOD

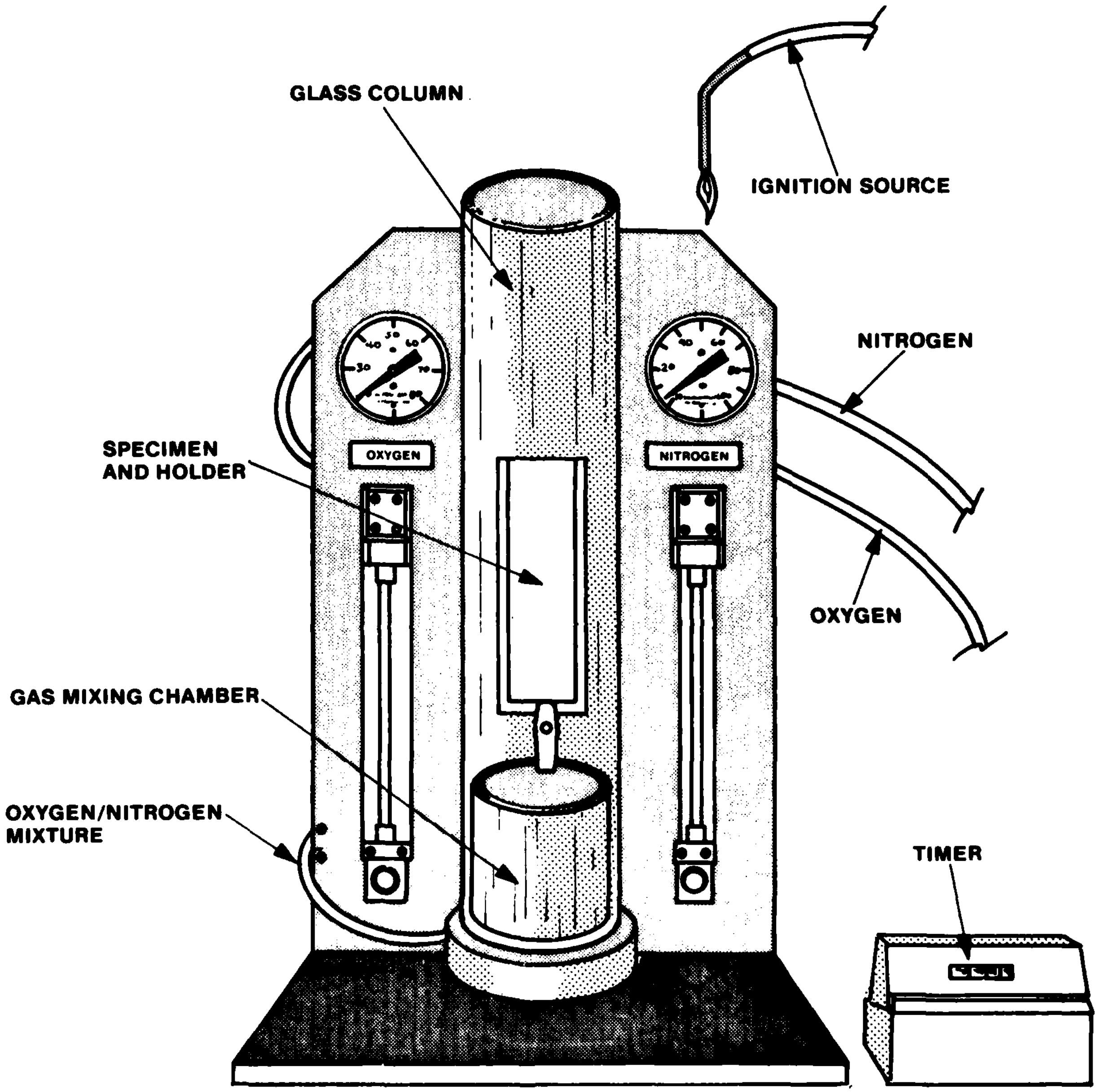

FIGURE 3. LIMITING OXYGEN INDEX TEST METHOD

Radiant Panel - This laboratory test is ASTM standard test method for surface flammability of materials using a radiant energy source (designation: E162-81a). This method of measuring surface flammability of materials essentially employs a radiant heat source, consisting of a 12- by 18-inch panel, and an inclined 6- by 18-inch specimen. The orientation of the specimen is such that ignition is forced near its upper edge and the flame front progresses downward. The incident heat flux to the specimen ranged from a maximum of 4.4 watts per square centimeter (W/cm^2) at the top to a minimum of 0.4 W/cm^2 at the bottom. A factor derived from the rate of progress of the flame front (F_s)and another related to the rate of heat evolution by the material (Q) are combined to provide a flame spread index (I_s).

The apparatus is essentially as shown in figure 4 and includes the following:

(1) A radiant panel with air and gas supply consisting of a porous refractory material vertically mounted in a cast iron frame, exposing a radiating surface capable of operating at temperatures up to 1500 degrees Fahrenheit (°F); (2) A specimen holder with observation marks filed on its surface to correspond with 3-inch interval lines on the specimen; (3) Framework for support of the specimen holder at a 30-degree angle from the radiant panel; (4) An acetylene-air pilot burner mounted horizontally near the top of the specimen holder to force ignition; (5) A steel exhaust stack housing eight chromel-alumel thermocouples connected in parallel for measuring rate of heat liberation by a material; (6) An automatic potentiometer recorder to record the temperature variation of the stack; (7) An exhaust hood; (8) A radiation pyrometer for standardizing the thermal output of the panel; (9) A portable potentiometer for measuring the output of the radiation pyrometer; and (10) a timer. Test duration is 15 minutes or until 15-inch flame spread has been achieved.

Ohio State University (OSU) Apparatus: The OSU apparatus was recognized by the SAFER advisory committee as the most meaningful, realistic, small-scale test available with regard to testing materials for cabin fire hazards (reference 2). This evaluation was based, in part, on a number of important features of the OSU apparatus, including the measurement of heat/smoke release rates, the recording of data as a function of time, and the capability of varing the incident heat flux. Moreover, the OSU has been instrumented to measure selected toxic gas emmissions, leading to the development of a combined Hazard Index (CHI) by the McDonnell Douglas Corporation during a study sponsored by the FAA (reference 10). The OSU apparatus is a standardized test device for measuring the rate of heat and smoke release from burning materials. It is described in detail in ASTM Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products (Designation: E906-83). Basically, a sample is exposed to controlled heating conditions and a known airflow rate inside a chamber (figure 5). Measurements taken in the exhaust stack are used to calculate the heat release rate as a function of time. The sample is subjected to a radiant heat source and upper and lower pilot flames. In this study, a 6- by 6-inch vertical sample was exposed to radiant heat at 2.5, 5.0 and 7.5 W/cm^2 using both pilots, and to radiant heat at 5.0 W/cm^2 without the lower pilot. The rate of heat release was calculated by both the thermopile and oxygen depletion methods. The thermopile measurement method was identical to that described in ASTM E906-83 except for baseline correction with a blank sample holder. The oxygen depletion method is a modification made to the OSU apparatus by FAA. Briefly, the concentration of oxygen in the inner pyramidal section is monitored continuously with an oxygen analyzer. The heat release rate is calculated from the depleted oxygen

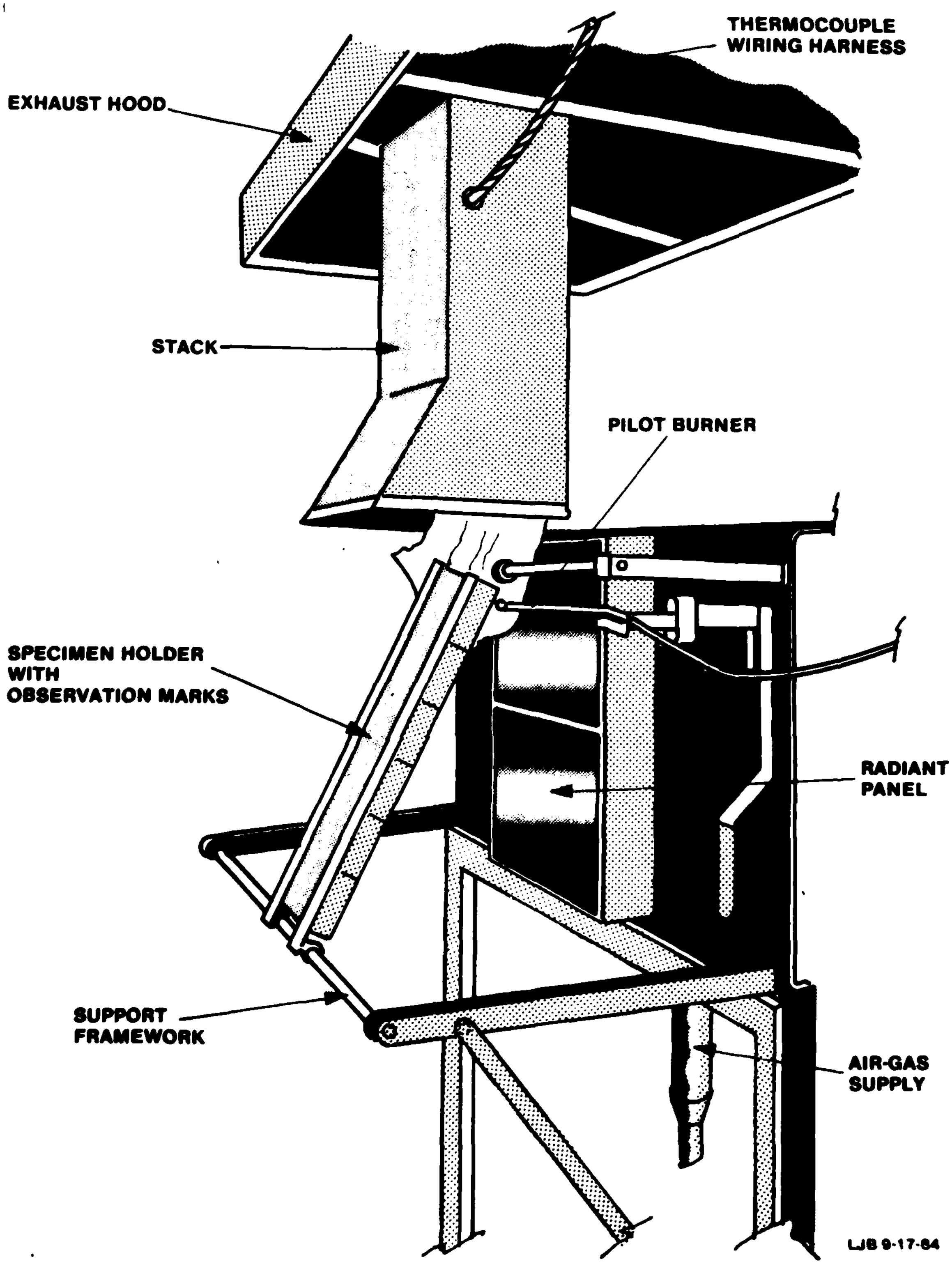

FIGURE 4. RADIANT PANEL TEST METHOD

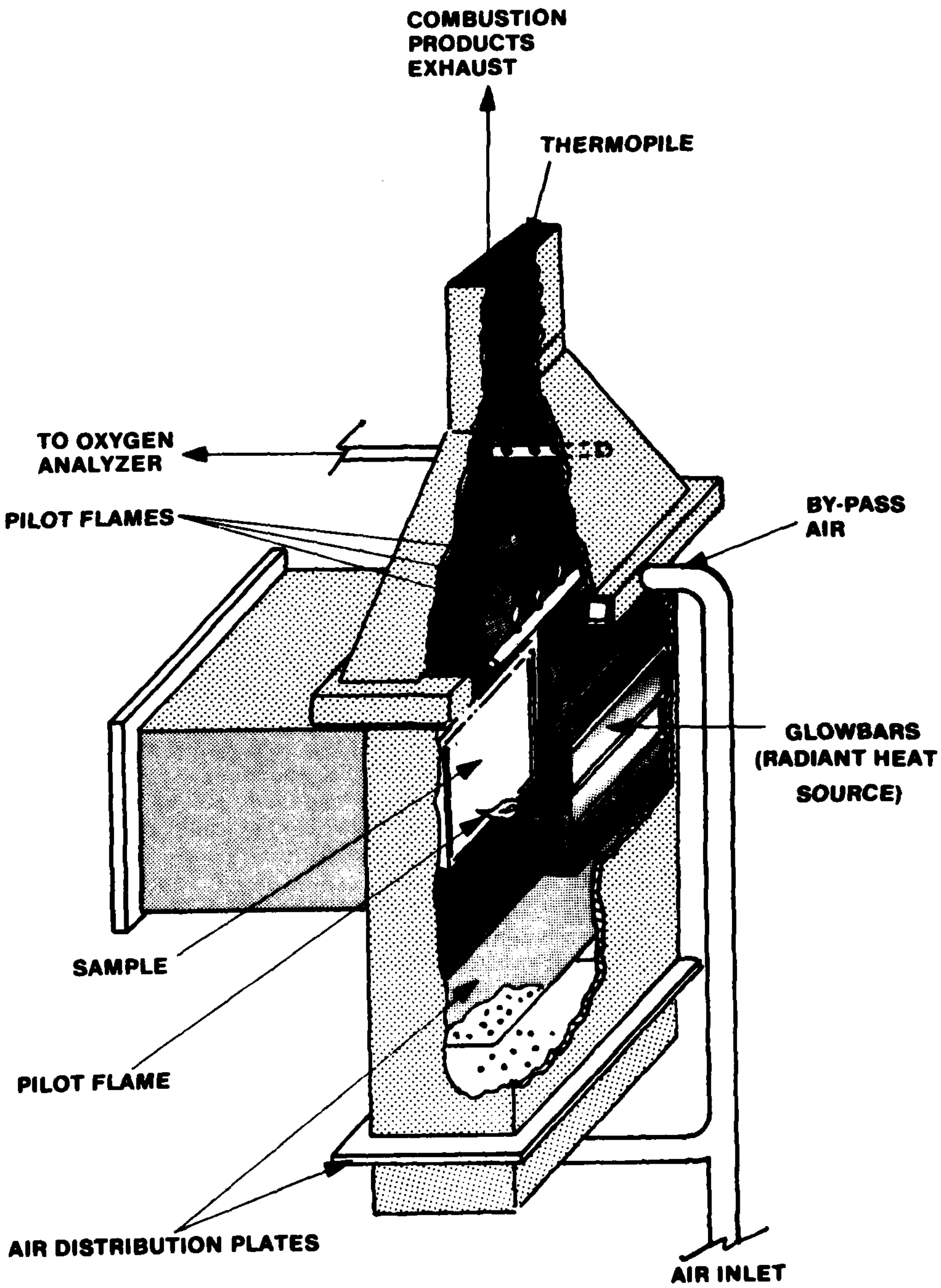

FIGURE 5. FAA OHIO STATE HEAT RELEASE APPARATUS

concentration and known airflow rate, utilizing a theoretical constant obtained from the literature (where it was demonstrated that the heat relaease by a burning polymer was approximately proportional to the amount of oxygen consumed). Although not a part of this study, the FAA has also modified the OSU apparatus to measure the release rate of selected toxic combustion gases (reference 11).

DESCRIPTION OF TEST PANELS.

A description of the test panels used for this study is contained in table 1. The panels were fabricated as flat sheets, 49 inches by 72 inches, for this study. The sheets were procured from General Veneer Manufacturing Company in South Gate, California. They are similar to the types of panels being used or under consideration for aircraft cabin interior applications, such as sidewalls, stowage bins, ceilings and partitions. Generally, aircraft interior honeycomb panels consist of four components: (1) outer decorative film, (2) resin-impregnated cloth facings, (3) adhesive, and (4) honeycomb core. For this study, the composition of the facings was varied in order to produce a range in fire performance, and consisted of epoxy and phenolic resins and fiberglass, Kevlar™, and graphite cloths. The decorative film and honeycomb core for each type of panel was 2-mil Tedlar™ and 1/4-inch thick, phenolic-dipped Nomex™, respectively.

TEST RESULTS AND ANALYSIS

ONE-FOURTH SCALE MODEL.

A total of 24-four tests were conducted with planned durations of 15 minutes each. In addition to the five honeycomb panels, a Kaowool board was tested in order to establish a reference against which to evaluate the materials.

During the testing of panel numbers 1 and 4, it was necessary to terminate the tests prematurely because the severity of the enclosure fire jeopardized the model and the instrumentation. It was also necessary to reinforce panel number 3, since it had a tendency to cave in at the burner end of the model. This was accomplished by securing two metal strips widthwise to the top of the ceiling panel, 11 inches from either side of the centerline of the burner pan.

Figures 6 and 7 contain representative temperature profiles for each panel type. Figures 8 and 9 contain representative heat flux profiles for each panel type, with the Kaowool profiles included as a reference.

The following characteristic was observed in all of the panels tested. The Tedlar surface above or near the fire separated and fell to the floor in small flaming pieces at 5 seconds into the test. It was noted that separation of the Tedlar surface in panels 1 and 3 did not make any sounds, while panels 2, 4, and 5 produced a popping noise. Thus, the popping was associated with the phenolic resin in the face sheet. This action occurred throughout the test in those areas where the Tedlar still remained secured to the panel. After the propane burner was shut off, the flames within the model quickly died out, reflecting the self-extinguishing nature of the materials.

In this report, the term "flame-over" refers to the appearance of flames in the model's ceiling area. The term "flashover" refers to the time at which the paper ignites. The term "zero visibility" refers to the density of the smoke at which time the fire can no longer be seen when viewed through the front door at a distance of 8 feet from the fire.

TABLE 1. DESCRIPTION OF TEST PANELS

No.	Designation	Description
1	EP/FG	Epoxy glass facings, face and back 1-ply 7781 fiberglass impregnated with epoxy resin, fire retardant, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2 mil white Tedlar™. Wt. = 0.36 lbs/sq. ft.
2	PH/FG	Phenolic glass facings, face and back 1-ply 7781 style woven fiberglass impregnated with a modified phenolic resin, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex honeycomb. Outer surface covered with 2 mil white Tedlar. Wt. = 0.42 lbs/sq. ft.
3	EP/KE	Epoxy Kevlar™ facings, face and back 1-ply 285 style woven Kevlar impregnated with epoxy resin, fire retardant, and co-cured to 1/8 cell, 1.8 lb, 1/4 inch-thick Nomex honeycomb. Outer surface covered with 2 mil white Tedlar. Wt. = 0.38 lbs per sq. ft.
4	PH/KE	Phenolic Kevlar facings, face and back 1-ply 285 style woven Kevlar impregnated with a modified phenolic resin and co-cured to 1/8 cell, 1.8 lb, 1/4 inch-thick Nomex honeycomb. Outer surface covered with 2 mil white Tedlar. Wt. = 0.38 lbs per sq. ft
5	PH/GR	Phenolic graphite facings, 1-ply 8 harness satin, 3K fiber T-300 woven graphite impregnated with a modified phenolic resin, and co-cured to 1/8 cell, 1.8 lb, 1/4 inch-thick Nomex honeycomb. Outer surface covered with 2 mil white Tedlar. Wt. = 0.36 lbs/sq. ft.

Note: Weight is based on nominal weight of the components.

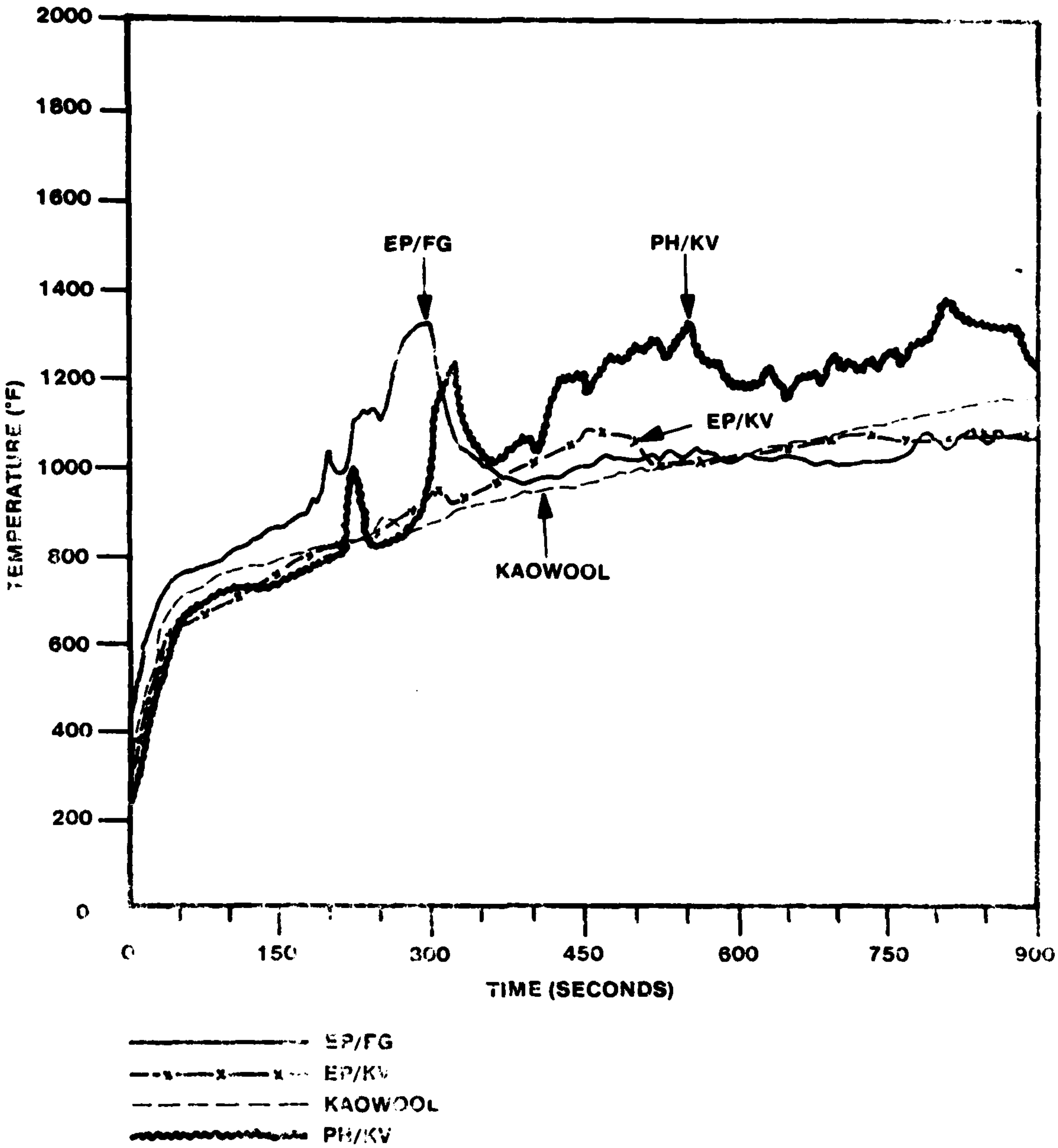

FIGURE 6. MODEL CEILING TEMPERATURE PROFILE FOR FLAMMABLE PANELS

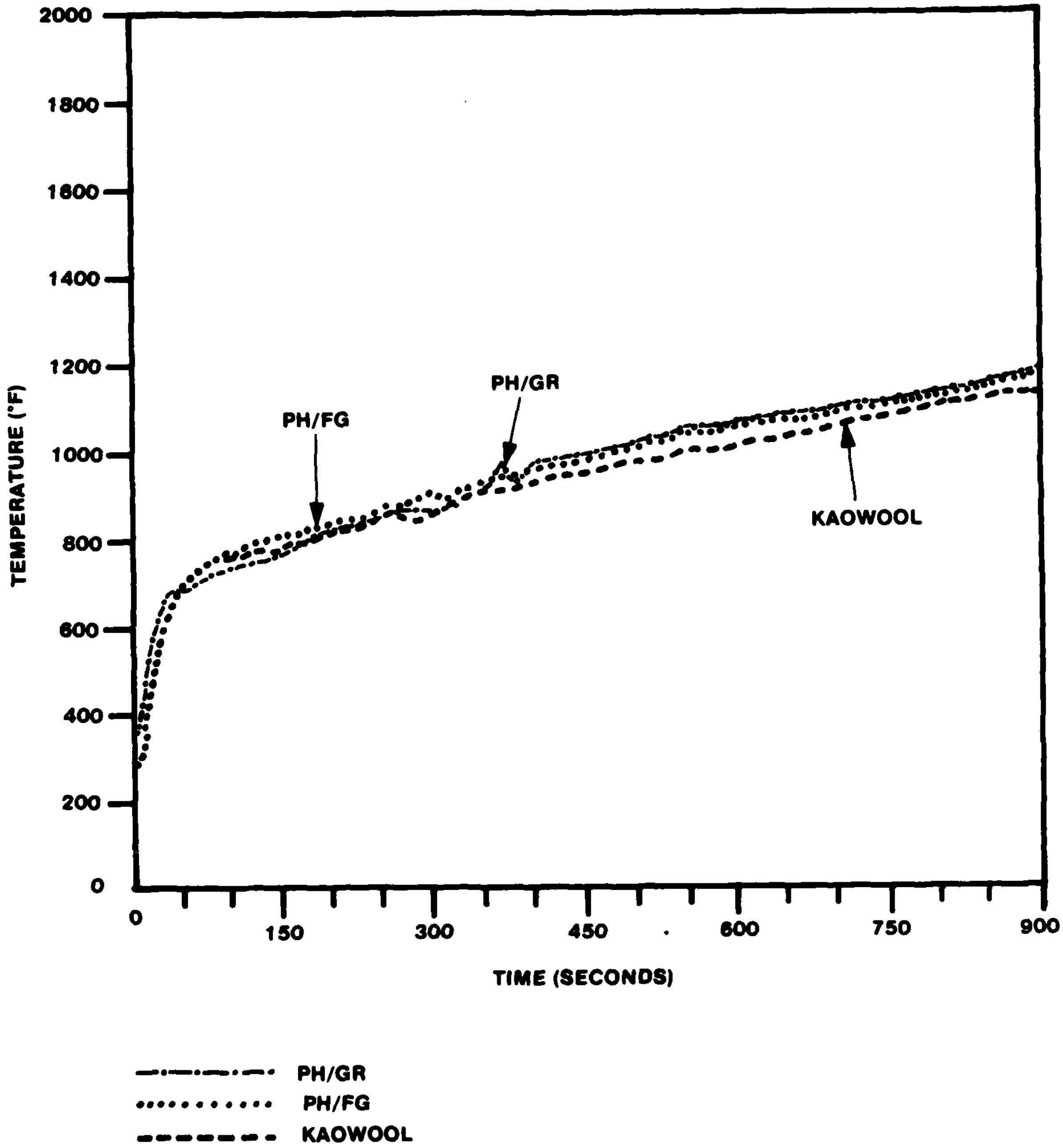

FIGURE 7. MODEL CEILING TEMPERATURE PROFILE FOR FIRE RESISTANT PANELS

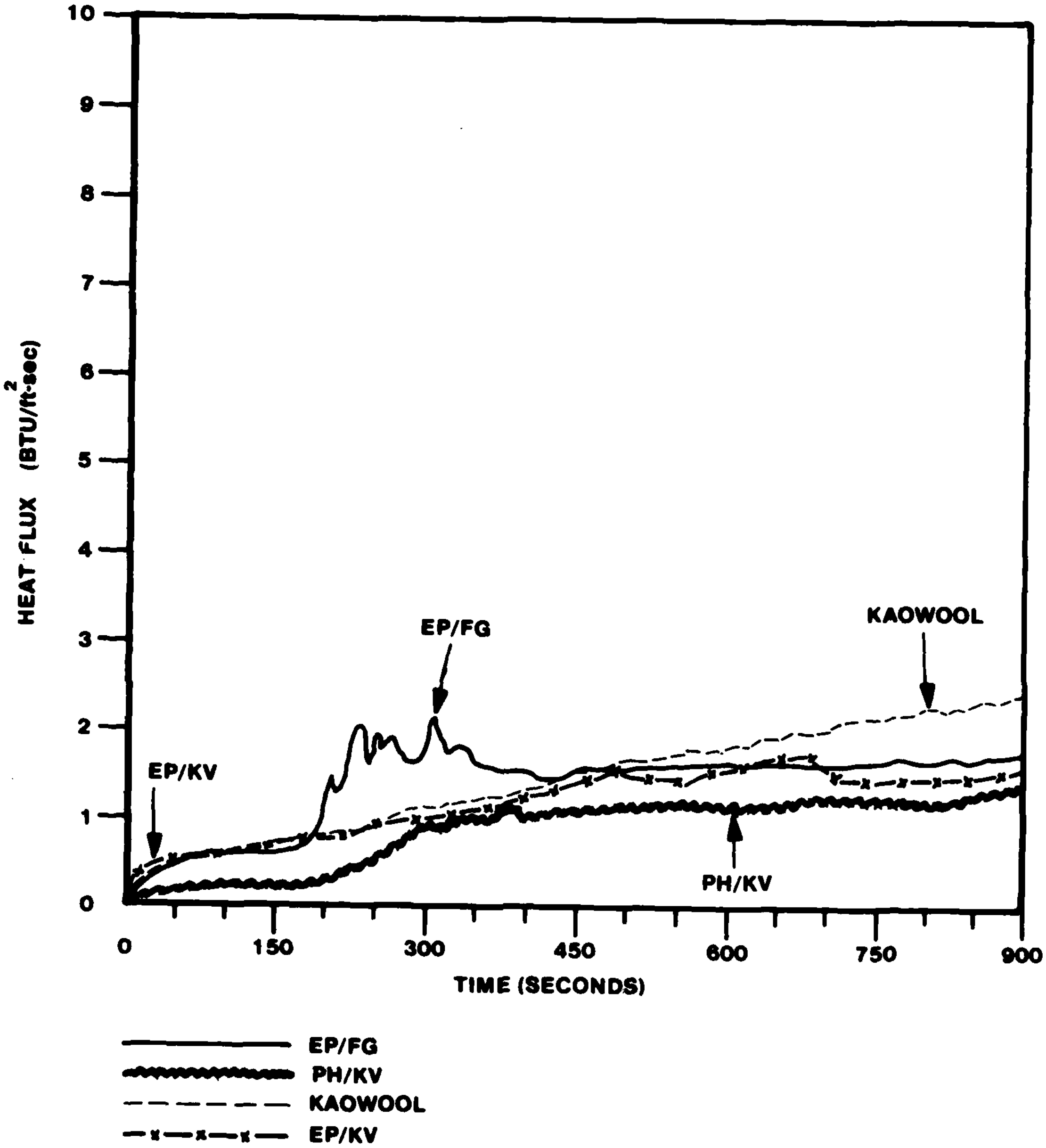

FIGURE 8. HEAT FLUX PROFILE FOR FLAMMABLE PANELS

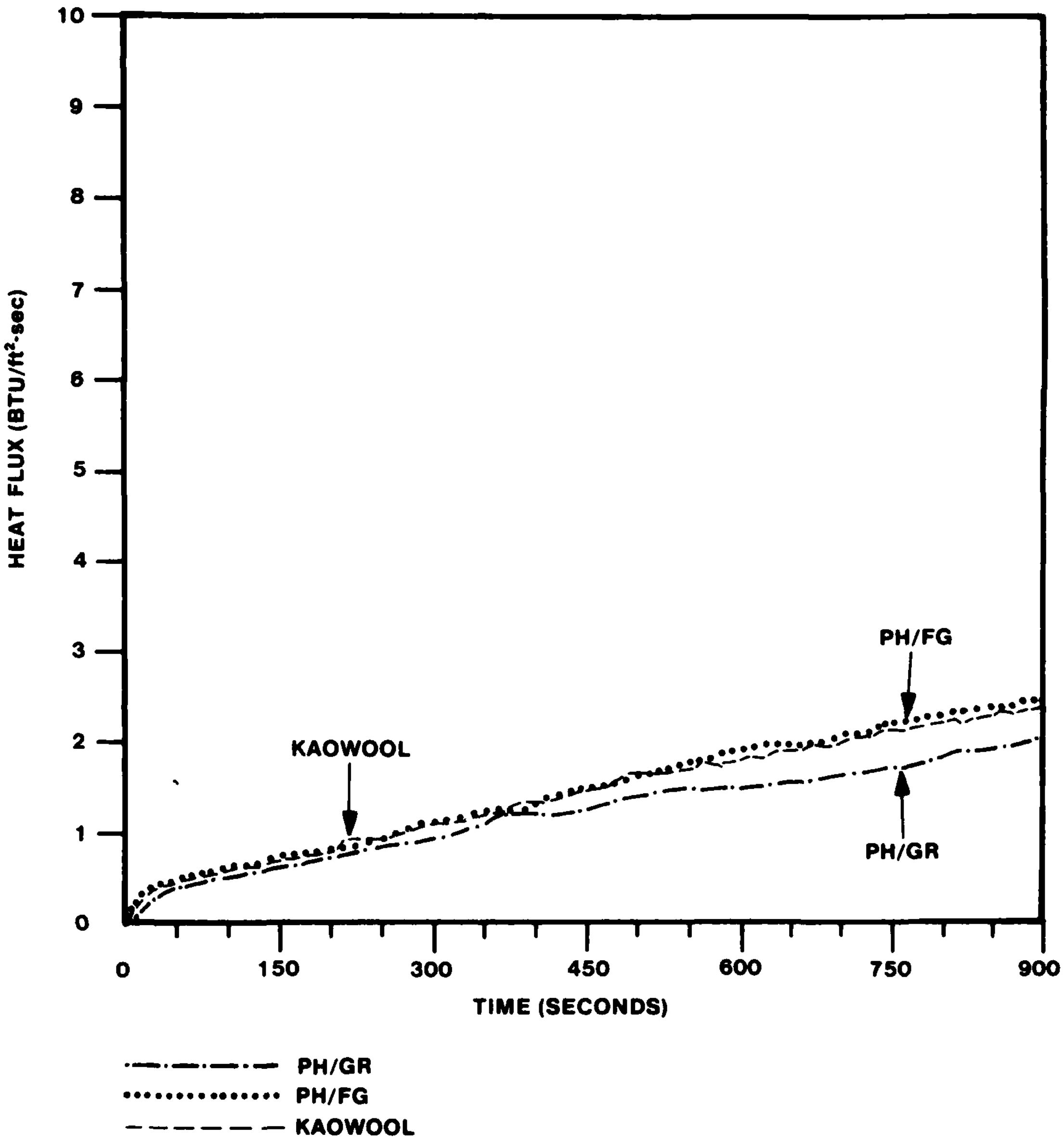

FIGURE 9. HEAT FLUX PROFILE FOR FIRE RESISTANT PANELS

Panel 1 (EP/FG) emitted a large quantity of heavy dark smoke, and it resulted in zero visibility for a period of 20 to 200 seconds into the test. After a partial clearing of the model at that time, the fire was once again visible. The paper ignited between 250 and 330 seconds into the test. This event can be seen in figure 8.

Panel 2 (PH/FG) exhibited a large quantity of heavy dark smoke, resulting in zero visibility for a period of 20 to 60 seconds into the test.

As in the case of panel 1, the model partially cleared of smoke at that time. The ignition of the paper occurred between 300 and 505 seconds into the test. Panel 2 had similar temperature and heat flux profiles as that of the Kaowool reference material (figures 7 and 9).

Panel 3 (EP/KV) when unsupported, produced a large quantity of dark heavy smoke resulting in zero visibility for the period between 20 and 150 seconds into the test. It also exhibited a tendency to cave in over the burner and disturb the burner plumes, resulting in erratic measurements. When the panel was supported, a large quantity of heavy dark smoke was produced between 120 and 240 seconds into the test. The temperature results were slightly higher than the Kaowool reference profiles (see figure 6).

Panel 4 (PH/KV) produced a large quantity of dark dense smoke, resulting in zero visibility 200 seconds into the test. This lasted several minutes before gradually leading to the interior being completely engulfed by fire just before the paper ignited. A flame-over condition was observed within the model. It was also observed that the phenolic/Kevlar material peeled away from the Nomex core in large sections. Flashover occurred 220 to 450 seconds into the test (figure 6).

Panel 5 (PH/GR) produced grey smoke that only slightly impaired visibility. The panel retained its shape throughout the test. Flashover occurred between 240 and 422 seconds into the test (figure 7).

The Kaowool board tests resulted in a grey smoke similar to that of panel 5. This smoke was produced by the propane burner and not the material. Flashover occurred between 252 and 350 seconds into the test (figure 7.)

Analysis of the test results showed that the time for paper ignition could not be correlated to all the panels. Additionally, there was no connection between the ignition times and the temperature/heat flux data obtained. The flashover phenomena were primarily associated with the heating of the enclosure by the propane fire. Even when the entire enclosure interior was covered with inert material, the flashover phenomena still occurred. These tests distinguish one panel from another, not by flashover results, but by the degree of panel involvement in the fire as evidenced in the thermal data.

In the tests of panels 2, 3, and 5, the ignition of the crumpled paper alerts us to a potentially dangerous situation, namely, that light combustible materials may ignite. In the tests of panels 1 and 4, the ignition of the paper indicates the start of an intense temperature rise followed by sustained burning of the panels.

A major consideration when trying to evaluate the panels is that the generic name used to identify the resin can refer to a range of possible materials. The actual properties of a given resin depends on the specific type of monomer, the cure cycle used, and additives like plasticizers and fire retardants.

Overall, it appears that phenolics are superior to epoxies and that graphite and fiberglass perform better than Kevlar.

The ranking system developed to rate panel performance is based on the severity of the internal fire and its ability to spread. The temperature profiles are representative of the interior burning conditions and in conjunction with the qualitative observations create an overall view of material performance. The materials were divided into three different categories: (1) Poor - those that resulted in an interior cabin fire; (2) Fair - those that resulted in localized flame-over near the burner; and (3) Good - those that showed no signs of flame-over (table 2). Under the poor category, epoxy/fiberglass was rated worse than phenolic/Kevlar due to its earlier occurrence of an interior cabin fire, despite the higher temperatures eventually reached by phenolic/Kevlar. Epoxy/Kevlar unsupported was rated poor because at the time of its collapse it resulted in a flashover. The securing of epoxy/Kevlar with reinforcement would place it in the fair category. Phenolic/fiberglass and phenolic/graphite were categorized as good because their temperature and heat flux profiles were virtually identical to these profiles for the noncombustible Kaowool board.

TABLE 2. PANEL FIRE PERFORMANCE RANKING IN ONE-FOURTH SCALE MODEL

Category	Description	Material	Rank Order
Poor	Interior Cabin Fire	EP/FG	1
		PH/KE	2
		EP/KE	3
Fair	Localized Flame-Over	EP/KE*	3
Good	No Flame-Over	PH/FG**	4
		PH/GR**	4

* Supported
** Equal Ranking

DESCRIPTION OF SMALL-SCALE TEST RESULTS.

The results obtained with the vertical Bunsen burner indicated, as expected, that each of the five types of panels "self extinguished" and were compliant with FAR 25.853(a) (table 3). Moreover, each of the panels "self extinguished" before removal of the burner, indicating that flame time was not an effective discriminator for panel burning behavior. Examination of the burn length data leads to the following pattern: (1) larger burn lengths for panels containing epoxy resin than for phenolic-impregnated panels; (2) virtually no differences between fiberglass and Kevlar faced panels for the same resin system; and (3) superior performance by the phenolic/graphite panel.

TABLE 3. VERTICAL BUNSEN BURNER TEST RESULTS*

Designation	Burn Length (inches)	Flame Time** (secs)
EP/FG	3.8	0
PH/FG	3.1	0
EP/KV	3.8	0
PH/KV	3.0	0
PH/GR	1.7	0

* Average value based on 3 replicate tests
** Zero values indicate flaming of sample ceased before burner removal

Limiting oxygen index test results (table 4) indicated that none of the panels would support flaming when subjected to a small ignition flame in air (21 percent oxygen). As was the case with the Bunsen burner test results, the phenolic-graphite panel exhibited the best behavior. Also, for the same type of cloth reinforcement material (fiberglas or Kevlar), the phenolic panels had a higher rating (better performance) than the epoxy panels. Finally, for the same type of resin (epoxy or phenolic), the fiberglas panels performed better than the Kevlar panels.

TABLE 4. LIMITING OXYGEN INDEX TEST RESULTS

Designation	Limiting Oxygen Index (%)
EP/FG	35.8
PH/FG	38.6
EP/KV	31.5
PH/KV	36.2
PH/GR	43.7

On the basis of the flame spread index, the radiant panel test results (table 5) indicated that the panel samples containing epoxy resin were generally more flammable than the panel samples containing phenolic resin. As expected, the highest heat production was from the panels containing epoxy and/or Kevlar. Somewhat surprising was the fact that the flame spread factor measured for the phenolic/glass panel was higher than for any of the other panels tested. Conversely, the phenolic/glass panel also had the lowest heat evolution factor. Overall, the flame spread index results appeared to fall into three groupings: high (epoxy/glass and epoxy/Kevlar), medium (phenolic/Kevlar) and low (phenolic/graphite and phenolic/glass).

TABLE 5. RADIANT PANEL TEST RESULTS*

Designation	Flame Spread Factor (F_s)	Heat Evolution Factor (Q)	Flame Spread** Index (I_s)
EP/FG	11.6	4.9	57
PH/FG	12.0	1.9	23
EP/KV	10.7	4.7	51
PH/KV	7.8	4.6	37
PH/GR	9.3	2.8	25

* Average value based on 3 replicate tests; screen used to retain specimen drippings

** $I_s = F_s \times Q$

There are many choices available for reducing heat release rate data obtained in the OSU apparatus for the purpose of evaluating the fire performance of a material. These data are a function of incident heat flux to the sample, the use or not of pilot flames, and the heat release measurement technique (thermopile or O_2 depletion). Moreover, at a given test condition or measurement technique, various forms of the data may be ultimately utilized. Peak heat release rate, or total heat release over any selected time interval may be used as the measurement criteria. Thus, compared to the limited number of output data from the previously discussed standardized test methods, the modified OSU apparatus provides a much greater choice of performance indicators. The key is to determine which of these indicators best reflects the performance of a material during a cabin fire. This, of course, was beyond the scope of this study.

The OSU apparatus was operated at four test conditions. The data are contained in table 6, and includes peak heat release rate and total heat release at 3 minutes for each test condition, measured by both the thermopile and oxygen depletion methods. Figures 10 to 13 show the effect of incident heat flux (piloted tests only) on the heat release data. Examination of these figures and table 6 resulted in the following main observations:

(1) Rank ordering of materials is dependent upon (a) incident heat flux to the sample, (b) usage or not of a pilot flame on the sample, (c) data output (peak heat release rate or total heat release over a specified time interval), and (d) measurement technique (thermopile or O_2 depletion method);

(2) With the exception of one condition, the phenolic/glass panel had the best ranking (lowest heat release) of the five panels tested at all piloted incident heat flux levels and for both forms of output data and measurement techniques;

(3) Total heat release increased monotonically with increasing incident heat flux for all materials tested and for both measurement techniques;

TABLE 6. OSU RATE OF HEAT RELEASE RATE TEST RESULTS*

	$2.5 W/CM^2$, P				$5.0 W/CM^2$, P				$5.0 W/CM^2$, N				$7.5 W/CM^2$, P			
	Therm.		O_2		Therm.		O_2		Therm.		O_2		Therm.		O_2	
	Peak	Total	Peak	Total	Peak	Total	Peak	Total	Peak	Total	Peak	Total	Peak	Total	Peak	Total
EP/FG	41.9	1.0	52.1	0.97	73.2	2.13	152.3	3.03	79.2	4.43	133.4	3.90	72.4	4.20	114.1	4.30
PH/FG	4.5	0.30	3.6	0.10	49.8	2.30	61.7	2.07	65.7	4.30	53.3	2.63	65.9	3.60	73.2	3.30
EP/KV	23.4	0.83	23.6	0.80	56.9	2.97	81.7	3.17	61.1	5.20	66.8	3.47	75.7	6.00	82.5	5.50
PH/KV	9.3	0.70	10.4	0.77	68.0	4.47	86.1	3.90	65.1	5.07	61.7	3.37	89.8	7.10	112.4	5.60
PH/GR	10.1	0.53	10.8	0.57	64.8	3.03	75.6	2.67	67.8	3.47	60.3	2.67	87.6	4.90	104.1	3.90

*Average value based on 3 replicate tests

Notes: P = Piloted, N = Non-piloted
Therm = Thermopile measurement
O_2 = Oxygen depletion measurement
Peak = Peak Heat Release Rate, KW/M^2
Total = Total Heat Release at 3 mins, MJ/M^2

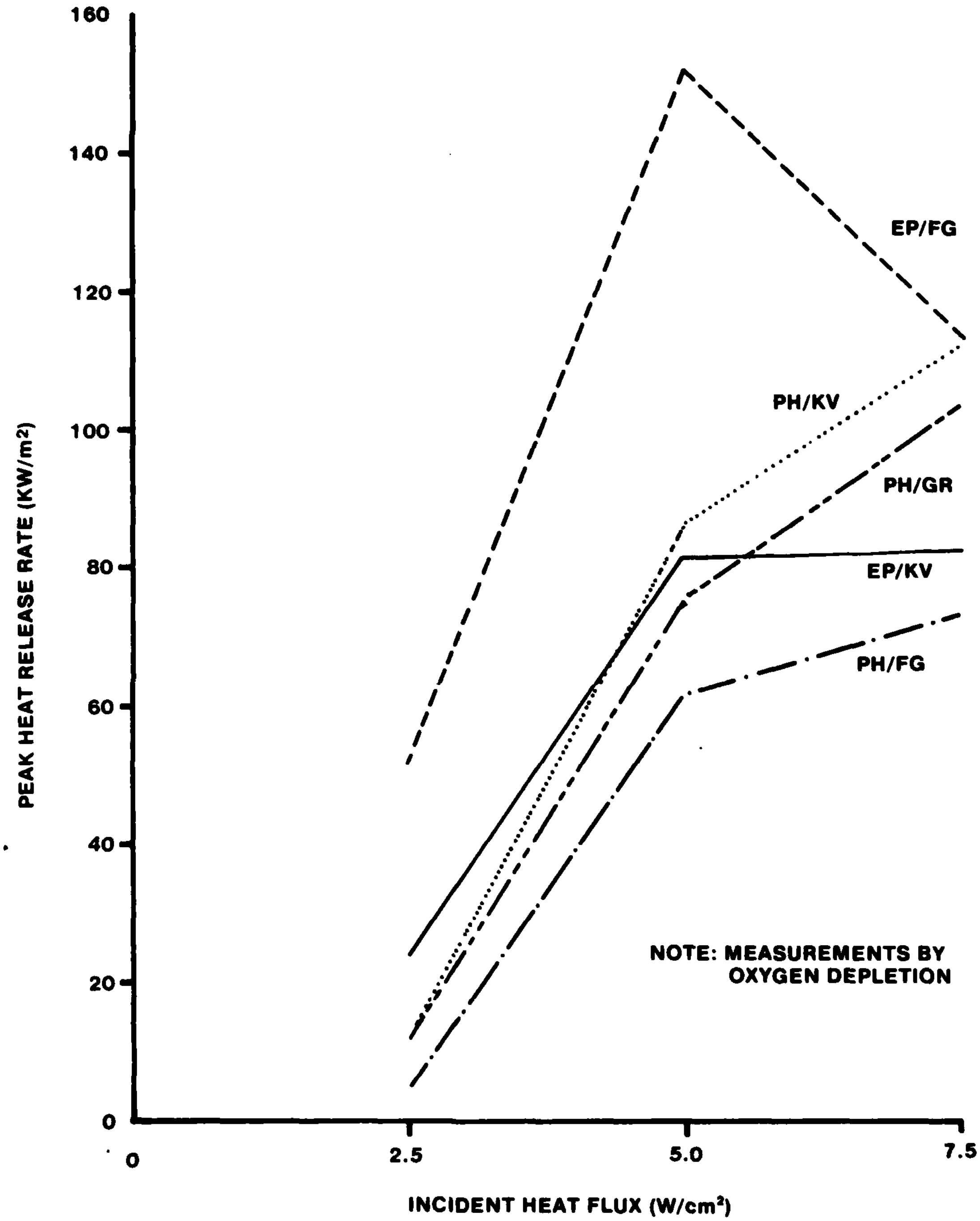

FIGURE 10. PEAK HEAT RELEASE RATE DATA (O_2 DEPLETION) FOR AIRCRAFT PANELS BY OSU APPARATUS

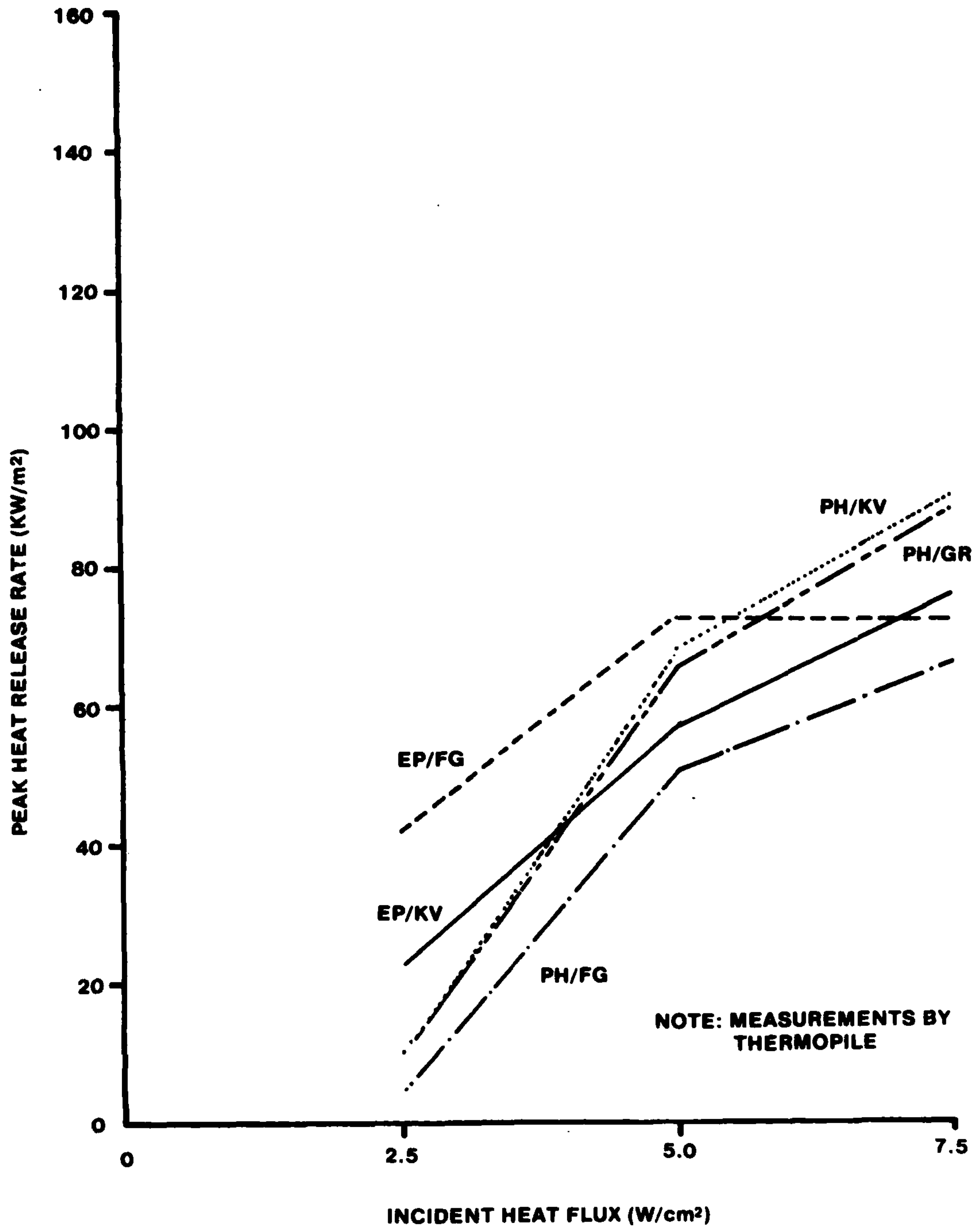

FIGURE 11. PEAK HEAT RELEASE RATE DATA (THERMOPILE) FOR AIRCRAFT PANELS BY OSU APPARATUS

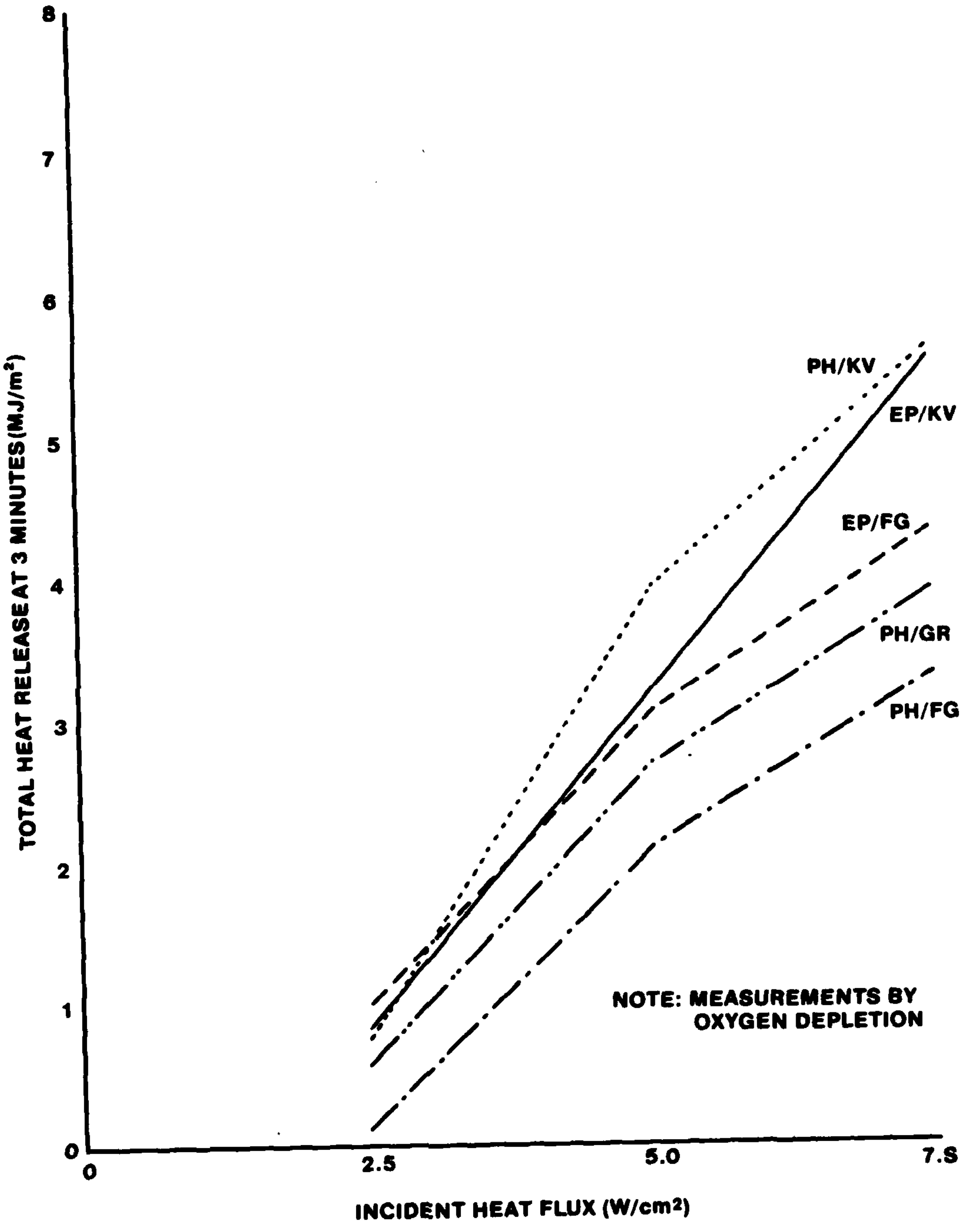

FIGURE 12. TOTAL HEAT RELEASE AT 3 MINUTES (O_2 DEPLETION) FOR AIRCRAFT PANELS BY OSU APPARATUS

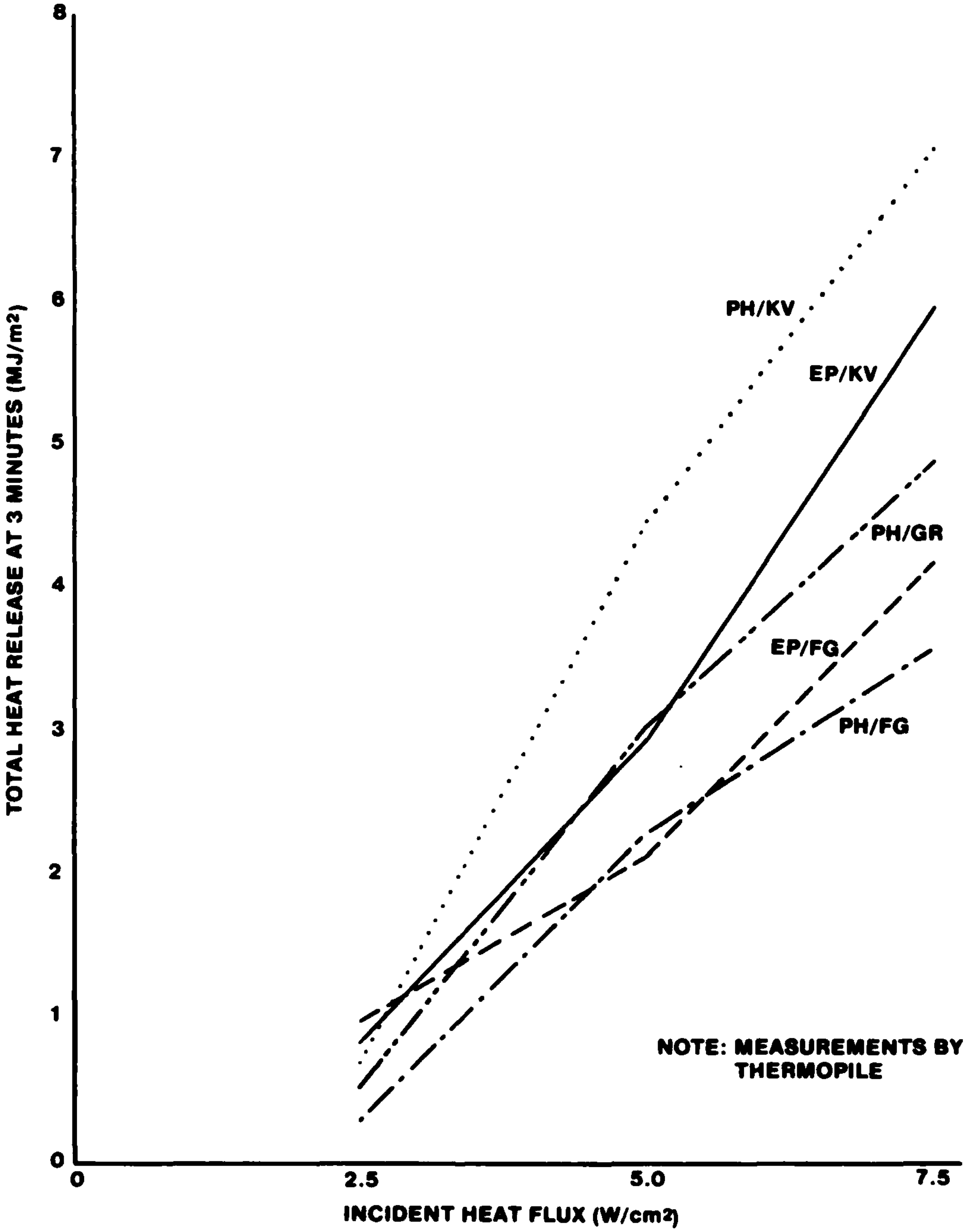

FIGURE 13. TOTAL HEAT RELEASE AT 3 MINUTES (THERMOPILE) FOR AIRCRAFT PANELS BY OSU APPARATUS

(4) Peak heat release rate increased monotonically with increasing incident heat flux for both measurement techniques and for all material tested with the exception of the epoxy/fiberglass panel.

A comparison was made of the thermopile and oxygen depletion measurement techniques employed in the OSU apparatus. Figure 14 compares the measurement techniques on the basis of peak heat release rate and total heat release for all materials and at all test conditions. For peak heat release rate, the oxygen depletion method exceeds the thermopile method, and the difference in measured peak heat release rate by these methods becomes greater as the peak heat release rate increases. A plausible explanation for this behavior is that for sudden increases in heat release, a significant portion of that additional heat release is transferred to the walls of the chamber and is not detected by the thermopile. This results in a loss of sharpness in the peak, whereas oxygen measurements have none of the lag associated with thermal measuement techniques. For total heat release, the oxygen and thermopile measurements are more nearly equivalent, although at higher heat release values the thermopile measurements tended to be higher than the oxygen depletion measurements.

COMPARISON BETWEEN MODEL AND SMALL-SCALE FIRE TEST RESULTS.

The purpose of this study was to determine if small-scale fire tests can predict the relative behavior of different panel materials tested in a 1/4-scale cabin model. The comparison between small-scale and model test results was made strictly on the basis of rank order of materials performance. The superior performance of the phenolic/glass and phenolic/graphite panels in the 1/4-scale model could not be differentiated between, in order to establish an absolute ranking for the 5 test panels.

Table 7 compares materials ranking order between the 1/4-scale model and the three commonly-used standardized small-scale test methods evaluated during this study; viz, the Vertical Bunsen burner, limiting oxygen index and radiant panel test methods. Ranking order from the small-scale test methods was established from the following measurements:

- o Vertical Bunsen burner - burn length
- o Limiting oxygen index - O_2 concentration for burning
- o Radiant panel - flame spread index

It is evident that none of the standardized small-scale test methods correctly predicted the rank order of materials determined by the 1/4-scale model results. The main problem is that the standardized test methods consistently ranked the panels containing phenolic resin better than the panels containing epoxy resin. However, in the 1/4-scale model, the major departure from the small-scale results was in the ranking of the phenolic/Kevlar and epoxy/Kevlar panels. From the model tests it was clear that the epoxy/Kevlar panel performed better than the phenolic/Kevlar panel.

Of the three standardized test methods compared in table 7, the radiant panel gave the better agreement for materials ranking with the model ranking results. Perfect agreement between radiant panel and model ranking of materials would have existed if the epoxy/Kevlar and phenolic/Kevlar results had been simply transposed. Thus, the radiant panel is the most promising of these three standardized test methods. Apparently, the radiant panel is a more relevant test method because of

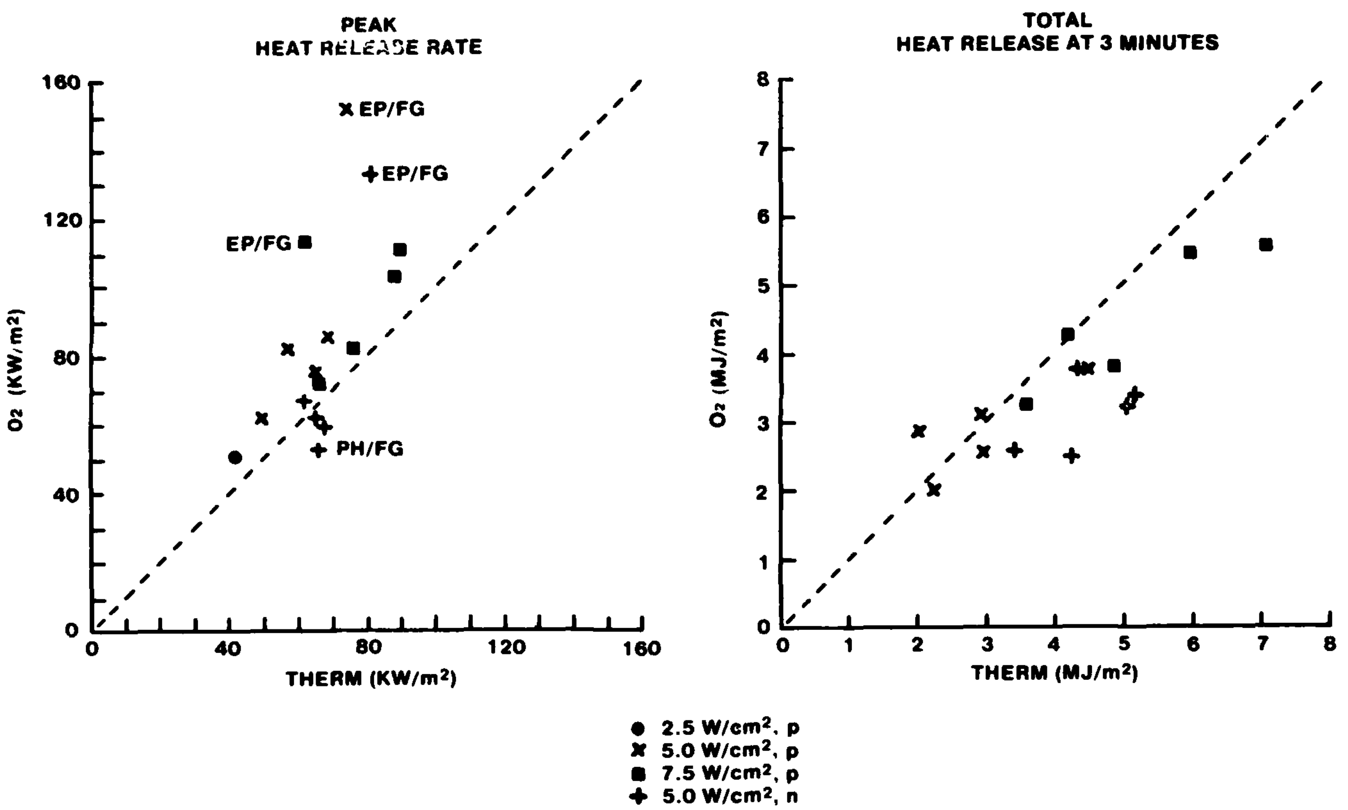

FIGURE 14. COMPARISON OF HEAT RELEASE MEASUREMENTS BY THERMOPILE AND O_2 DEPLETION METHODS IN OSU APPARATUS

the types of measurements taken (rate of flame spread and heat release) and because of the use of more intense exposure conditions (as high as 4.4 W/cm^2).

TABLE 7. RANK ORDER COMPARISON BETWEEN MODEL AND STANDARDIZED SMALL-SCALE FIRE TEST RESULTS

	Rank Order	1/4-Scale Model	Standardized Small-Scale Fire Tests Vertical (FAR 25.853)	LOI (ASTM D-2863)	Radiant Panel (ASTM E-162)
BEST	1	PH/FG or PH/GR	PH/GR	PH/GR	PH/FG
↑	2	PH//FG or PH/GR	PH/KV	PH/FG	PH/GR
	3	EP/KV	PH/FG	PH/KV	PH/KV
↓	4	PH/KV	EP/KV or EP/FG	EP/FG	EP/KV
WORST	5	EP/FG	EP/KV or EP/FG	EP/KV	EP/FG

EP/FG Epoxy Fiberglass
PH/FG Phenolic Fiberglass
EP/KV Epoxy Kevlar
PH/KV Phenolic Kevlar
PH/GR Phenolic Graphite

Figures 15 to 18 compare ranking of materials for fire performance between the 1/4-scale model and OSU apparatus. A total of 16 comparisons were made, consisting of four exposure conditions and 4 heat release measurements at each condition. An overall examination of the figures lead to two major findings. First, although a perfect correlation was found at only one combination of conditions and measurements, an exposure of 5 W/cm^2 produced a better comparison between model and OSU apparatus than did an exposure of 2.5 or 7.5 W/cm^2. This finding is simply based on counting the number of points on the perfect correlation line. Second, the phenolic/fiberglas panel was correctly predicted as the "best" material by OSU apparatus results at 14 of 16 condition/measurement combinations. Thus, the phenolic/fiberglass panel had excellent performance relative to the other panels when tested over a range of test conditions and heat release measurement parameters.

At 2.5 W/cm^2 each measurement parameter correctly indicated that the phenolic/fiberglass and epoxy/fiberglass panels gave the best and worst ranking, respectively. Also, for either peak heat release rate or total heat release, the same

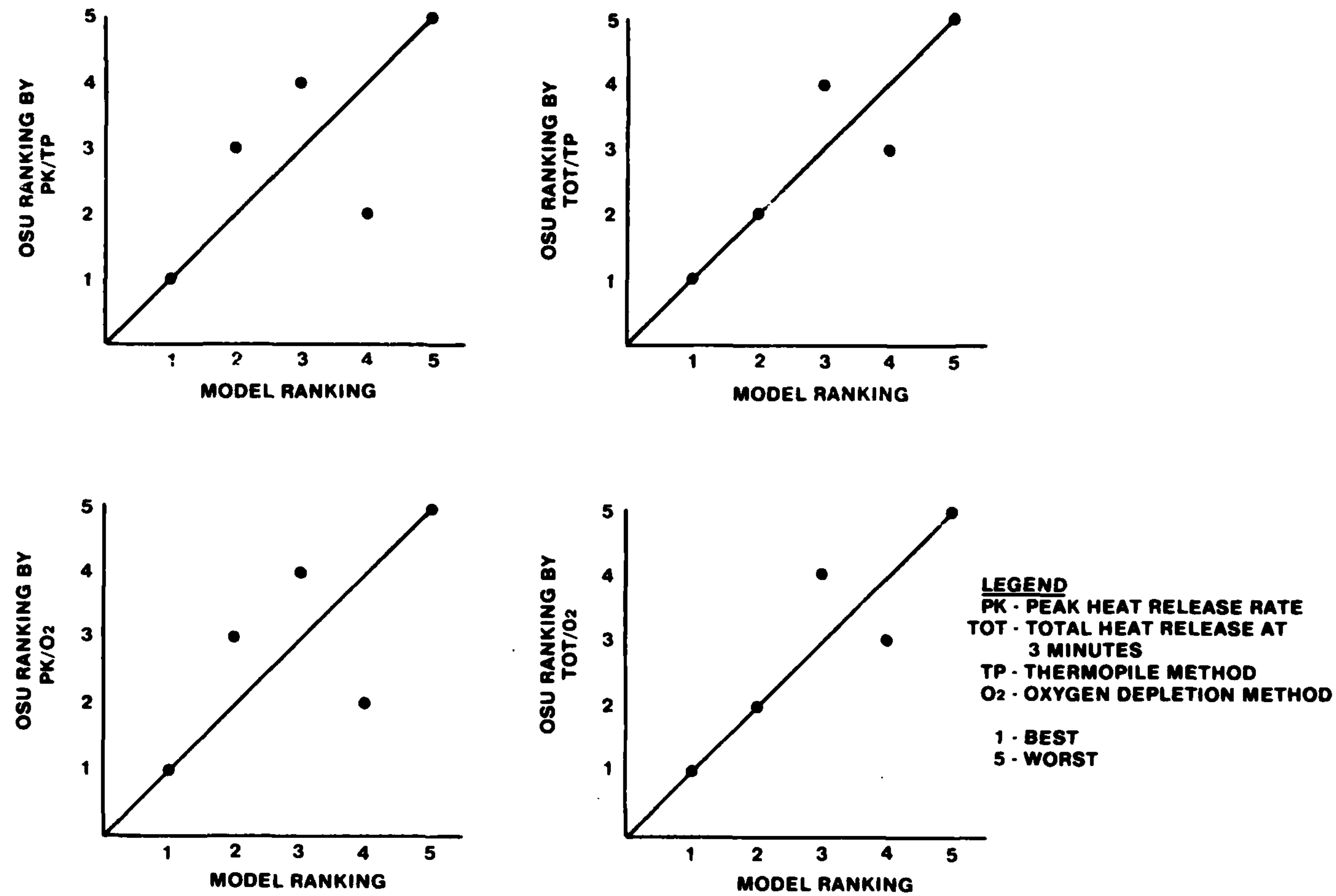

FIGURE 15. COMPARISON OF MATERIALS RANKING BETWEEN MODEL AND OSU APPARATUS AT 2.5 W/CM^2, PILOTED

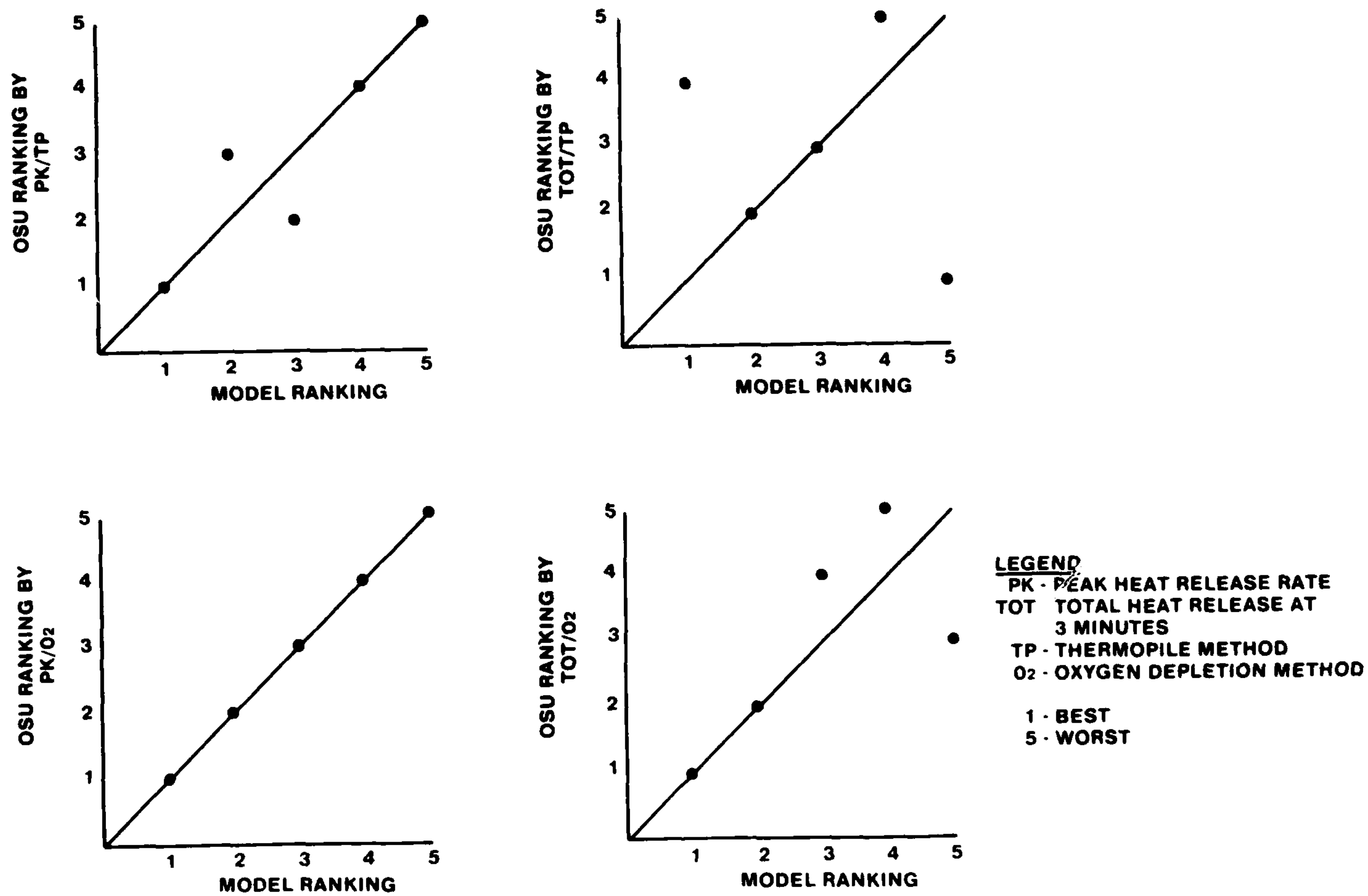

FIGURE 16. COMPARISON OF MATERIALS RANKING BETWEEN MODEL AND OSU AT 5.0 W/CM^2, PILOTED

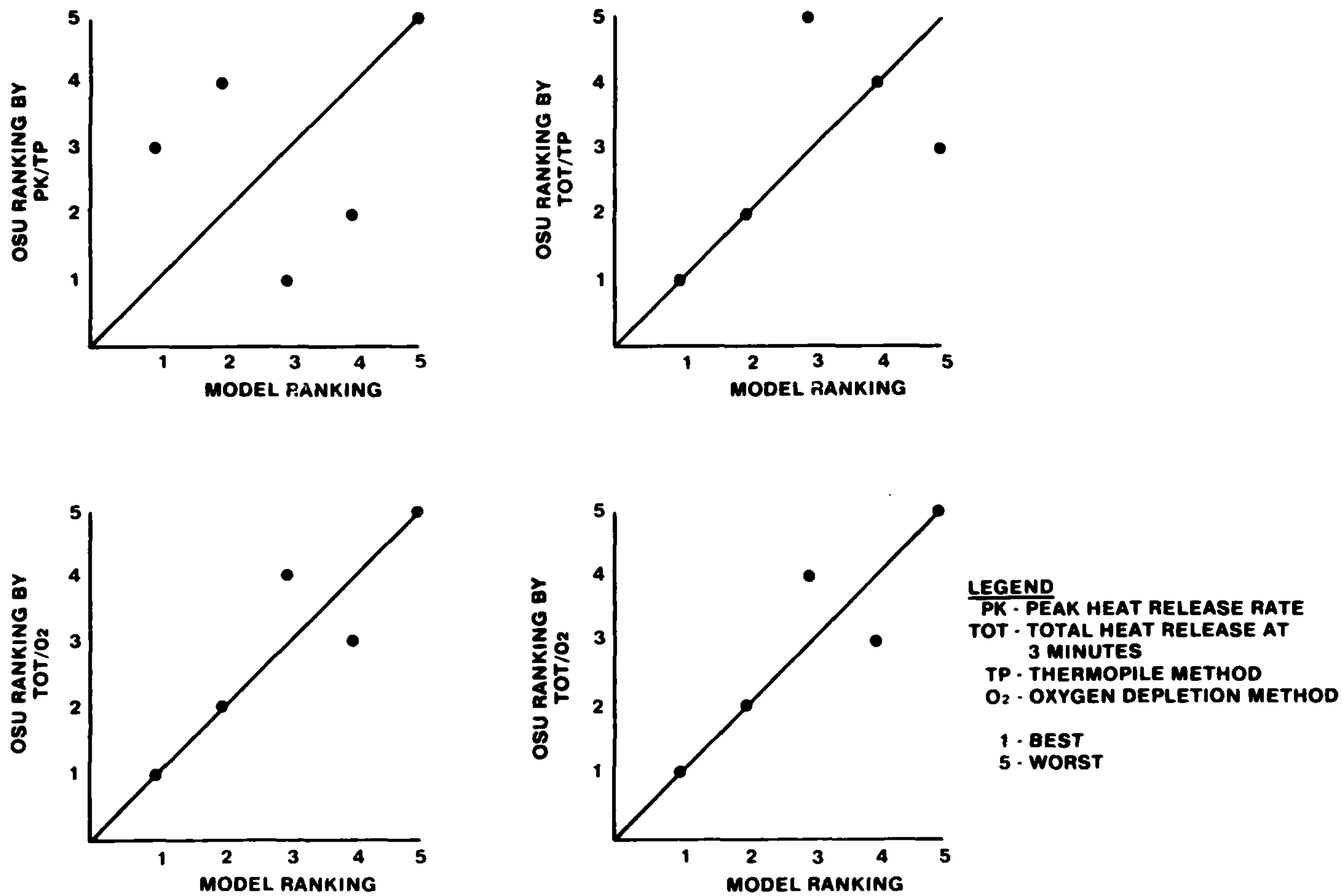

FIGURE 17. COMPARISON OF MATERIALS RANKING BETWEEN MODEL AND OSU APPARATUS AT 5 W/CM^2, NON-PILOTED

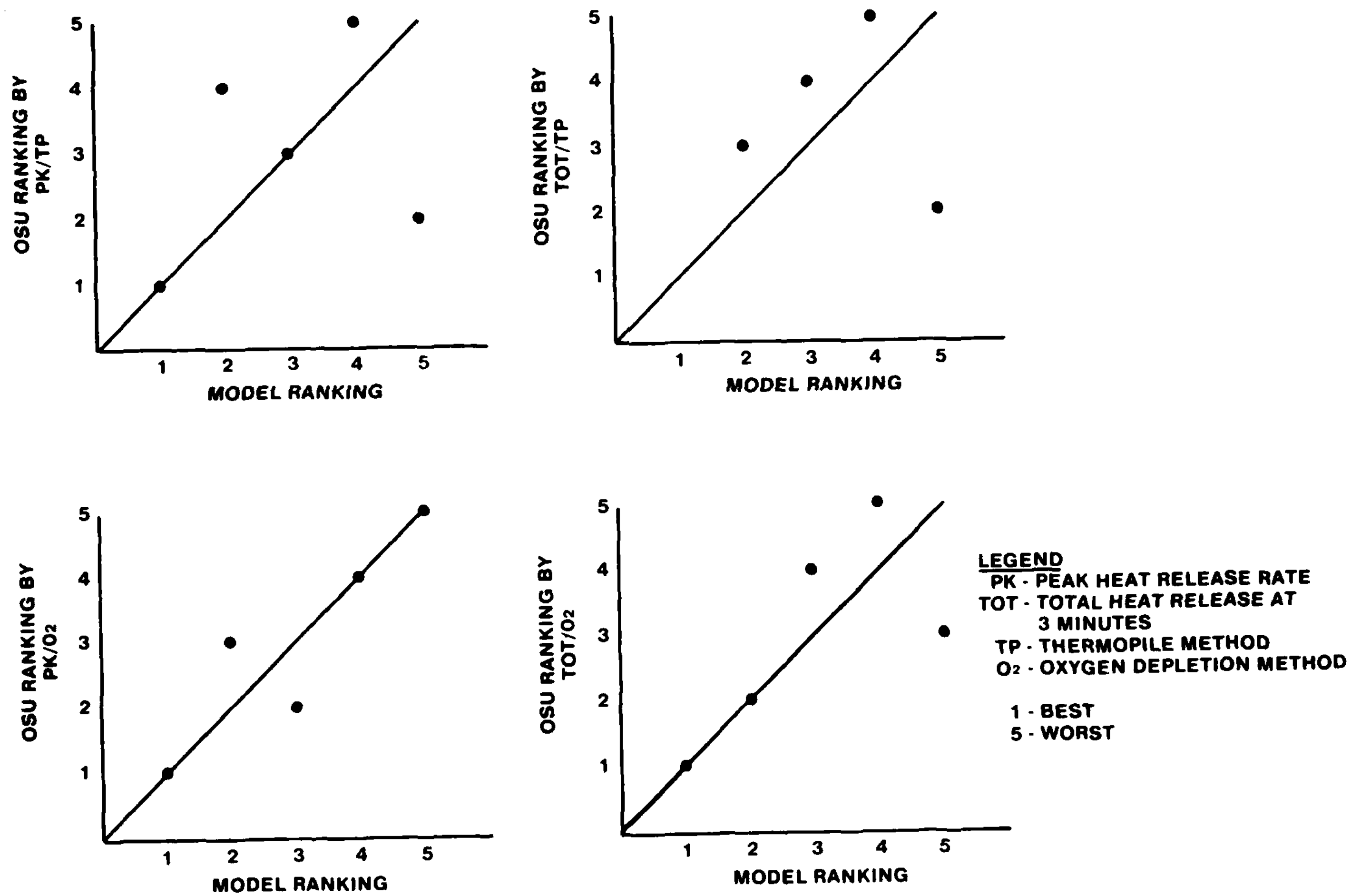

FIGURE 18. COMPARISON OF MATERIALS RANKING BETWEEN MODEL AND OSU APPARATUS AT 7.5 W/CM^2, PILOTED

rank ordering of materials was obtained by both the oxygen depletion and thermopile measurement techniques. Evidently, the good agreement between oxygen depletion and thermopile measurements at 2.5 W/cm^2 is due to the relatively low heat release rate at this condition (table 6). A heat flux of 2.5 Watts/cm^2, however, is too low an exposure level to use, primarily because the phenolic/Kevlar panel is relatively inactive at this condition, particularly when compared to the epoxy/Kevlar and epoxy/fiberglas panels.

The only perfect agreement between model and small-scale test ranking of materials was obtained at 5.0 W/cm^2, piloted, using peak heat release rate measured by oxygen depletion. Intuitively, peak heat release rate should be a proper parameter for hazard assessment because it relates to the maximum burning rate of the material. Although total heat release is perhaps equally promising as a candidate parameter, figure 16 indicates that total heat release results at 5.0 W/cm^2 may be misleading. For example, the epoxy/fiberglass panel which was ranked as the worst materials based on model test results, was rated as the "best" material in accordance with total heat release by thermopile measurement. Because the total heat release over 3 minutes is composed in large part of a component - following the peak release rate pulse - which is only slightly above the noise level of the apparatus, the accuracy of the total heat release measurement is somewhat questionable. Moreover, it was observed that the variability from replicate tests was much greater for total heat release than for peak heat release rate. Therefore, it appears that peak heat release rate is a better parameter than total heat release for the purpose of ranking the fire performance of interior materials.

A comparison of piloted and non-piloted test results at 5 W/cm^2 indicated that pilot flames can affect the ranking of materials. The piloted exposure condition appears to be more realistic than the non-piloted condition.

The poorest correlation between model and OSU apparatus ranking of materials was obtained at 7.5 W/cm^2. This test condition is much greater than the maximum heating rates generated in the 1/4-scale model and is also greater than the characteristic heating rates expected within an aircraft cabin fire. As shown in table 6, heat release at this elevated exposure condition is most dependent upon the amount of combustible material in the panel. Higher heat release rate values were obtained with panels containing Kevlar, and in some cases with the graphite panel, than with the two types of panel containing non-combustible fiberglass.

Of the three exposure conditions used in the OSU apparatus for this study, 2.5, 5.0, and 7.5 W/cm^2, the mid-heating condition (5.0 W/cm^2) produced the best comparison with model results for ranking the fire performance of materials. A heating rate of 2.5 W/cm^2 was too low, as evidenced by the low fire involvement of the phenolic/Kevlar panel. Conversely, a heating rate of 7.5 W/cm^2 was too high, as evidenced by the dependency of heat release on total combustible contents of the panel. Going beyond simple ranking of materials revealed, as shown in table 6, that even at the conditions/measurements producing a perfect comparison (peak heat release rate by oxygen depletion at 5.0 W/cm^2) the absolute data is not adequately spread out to match the modeling results. Ideally, for example, the phenolic/Kevlar panel should produce data that is closer to the epoxy/fiberglass results and further displaced from the results for the remaining panels, particularly the phenolic/fiberglass and phenolic/graphite panels. An exposure condition more closely matching the 1/4-scale model may have been between 2.5 and 5.0 W/cm^2.

COMPARISON OF HEAT RELEASE RATE DATA.

In addition to the OSU apparatus, the heat release rate for the five test panels was measured with the National Bureau of Standards (NBS) cone calorimeter and the Factory Mutual Research Corporation (FMRC) combustibility apparatus. The purpose of these tests was to compare heat release rate measurements made with these apparatuses on identical aircraft panels.

The three types of heat release rate apparatuses are essentially flow-through type of devices, in that the combustion products are continuously exhausted through a form of ducting wherein pertinent measurements are taken. However, there are important differences in the methods of sample exposure, containment of the combustion products/air mixture and heat release rate measurement which may have a bearing on the final test results.

The cone calorimeter exposes a material sample in either a vertical or horizontal orientation to a truncated conical heater (reference 12). Unlike the OSU apparatus, wherein forced ventilation passes across the heated sample mounted inside an enclosed chamber, the sample burn in the cone calorimeter takes place in open ambient air. The combustion products and induced air are drawn into an overhead hood which in turn is connected to exhaust ducting. The rate of heat release is calculated by the oxygen depletion method, using O_2 concentration and flow-rate measurements made in the exhaust ducting. For piloted ignition, a spark ignitor is employed above the sample, whereas, in the OSU apparatus two flaming pilots are employed, with one pilot impinging on the bottom surface of the sample and the other pilot being placed above the sample.

The FMRC combustibility apparatus exposes a horizontal material sample mounted inside a quartz tube to the radiant heat produced by four, coaxially placed tungsten-halogen quartz lamps (reference 13). The sample surfaces are blackened to reduce surface reflection by the predominantly short wave-length radiation of the quartz lamps. A small pilot flame near the sample surface ignites fuel vapors. Metered air is introduced at the bottom of the apparatus at a known rate. The bulk of the measurements are made in a vertical duct positioned above an exhaust collection cone, which captures the combustion products exiting from the quartz tube. The measurements relevent to this study include CO_2 concentration and temperature of the combustion mixture, used for the calculation of "actual" (total) and convective heat release rates, respectively.

Figure 19 compares the heat release rate measured by the three apparatuses for the five test panels. The cone calorimeter and combustibility apparatus data is contained in reference 13. The samples were oriented vertically in the OSU apparatus and cone calorimeter and horizontally in the FMRC combustibility apparatus. The data is based on three replicate tests in the OSU apparatus, two or three replicate tests in the cone calorimeter, and usually a single test in the FMRC combustibility apparatus. Heat release was determined by O_2 depletion in the OSU apparatus and cone calorimeter, and by CO_2 production in the FMRC combustibility apparatus. Although better agreement between the apparatuses or plausible explanations for disparities is desirable, the following observations are noteworthy:

- o The OSU data were consistently lower than either the cone calorimeter or combustibility apparatus data.

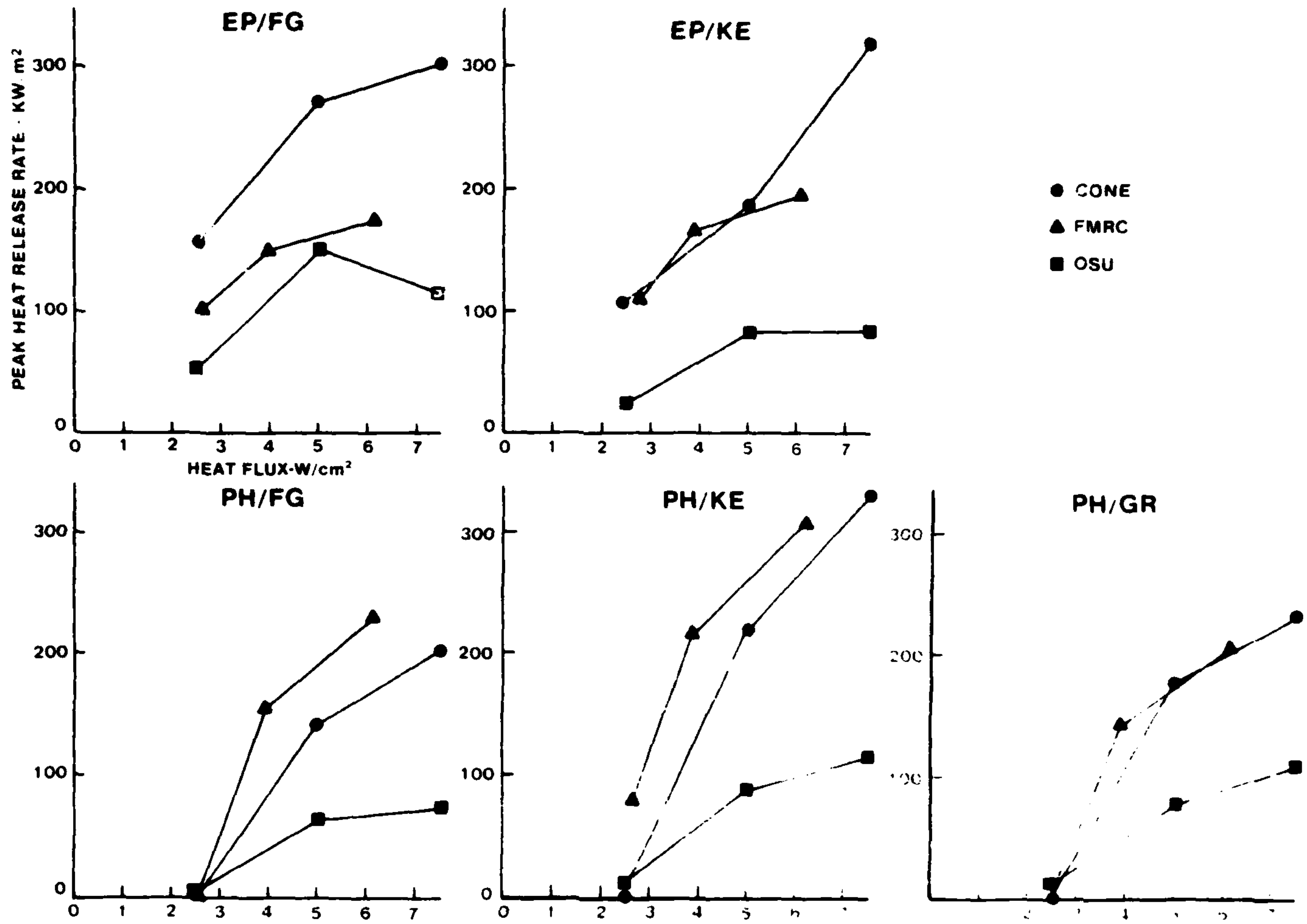

FIGURE 19. COMPARISON OF PEAK HEAT RELEASE RATE DATA IN OSU APPARATUS, CONE CALORIMETER AND COMBUSTIBILITY APPARATUS

o The combustibility apparatus data were usually greater or about equal to the cone calorimeter except for the epoxy/fiberglass panel.

o The phenolic/graphite and phenolic/fiberglass panels did not ignite or produced relatively low heat at 2.5 W/cm^2 for all three apparatuses.

o The phenolic/Kevlar panel, at 2.5 W/cm^2, produced virtually no heat in the OSU apparatus and cone calorimeter but significant heat release in the combustibility apparatus.

Of the three pairs of data, the OSU apparatus and cone calorimeter seem to be more consistent, based on the following results:

o Rank ordering of materials at 2.5 and 5 W/cm^2 is identical with the OSU apparatus and cone calorimeter.

o For the combustibility apparatus, the relatively low heat release rate for the epoxy fiberglass panel, compared to the other panels, is at odds with the results obtained with the OSU apparatus and cone calorimeter. (This result is also in conflict with the 1/4-scale model results which indicated that the epoxy fiberglass panel performed poorly.)

o For the combustibility apparatus, the heat release rate at 2.5 W/cm^2 for the phenolic/Kevlar panel is inconsistent with the low or zero heat release measured by the OSU apparatus and cone calorimeter. (This result is also in conflict with data obtained with the flame spread apparatus, indicating that the minimum heat flux necessary for ignition of the phenolic/Kevlar panel is 3.4 W/cm^2 (reference 13).

Since the above findings are based on a gross analysis of the data, more systematic studies are required to corroborate these findings and identify and correct, if necessary, the sources leading to any discrepancies between the three heat release rate apparatuses.

Figure 20 compares peak and total heat release rate data obtained at 5 W/cm^2 between the cone calorimeter and OSU apparatus. The results suggest that the data may differ by a constant factor in the range of 2.1 - 2.3. A possible reason for this factor is that the constant flow rate used to calculate the rate of heat release in the OSU apparatus is incorrect. In the cone calorimeter, the flow rate is measured directly.

Figure 21 compares the heat release rate measured by thermopile with the OSU apparatus and the FMRC combustibility apparatus for the five test panels. This data shows better agreement than the heat release rate measured by O_2 depletion and CO_2 production (figure 20), although significant differences are still evident for the epoxy/Kevlar and phenolic/Kevlar panels.

ANALYSIS OF FLAME-SPREAD APPARATUS TEST RESULTS.

In recent years the Bureau of Standards has supported and conducted research to understand and predict flame spread across solid materials. Broadly speaking, two distinct regimes have been identified - "creeping" flame spread (e.g., flame spread across a floor, or flame spread on a vertical wall in a lateral or downward direction) and wind-aided flame spread (e.g., flame spread across a ceiling or up a

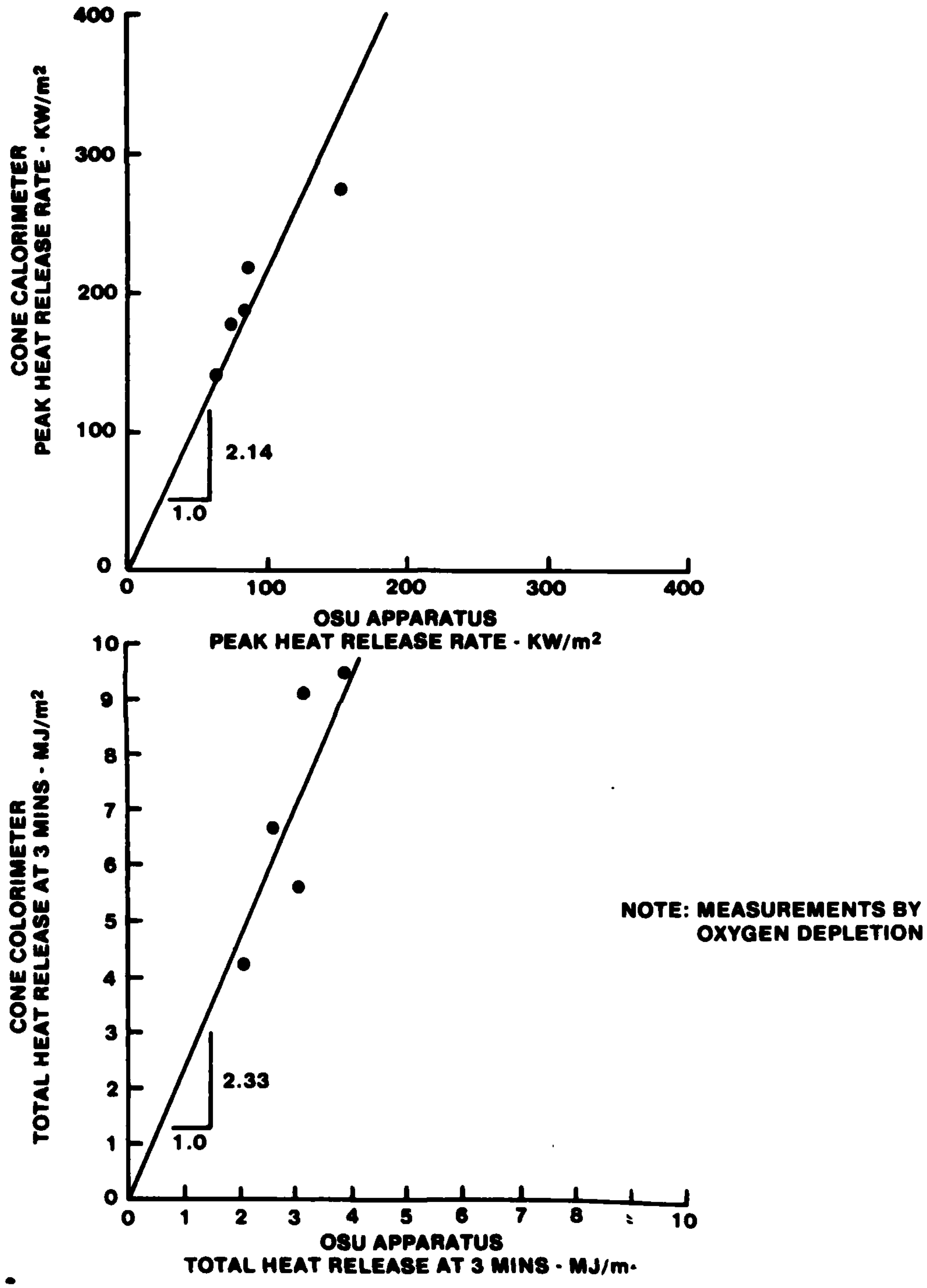

FIGURE 20. COMPARISON OF HEAT RELEASE DATA BETWEEN CONE CALORIMETER AND OSU APPARATUS

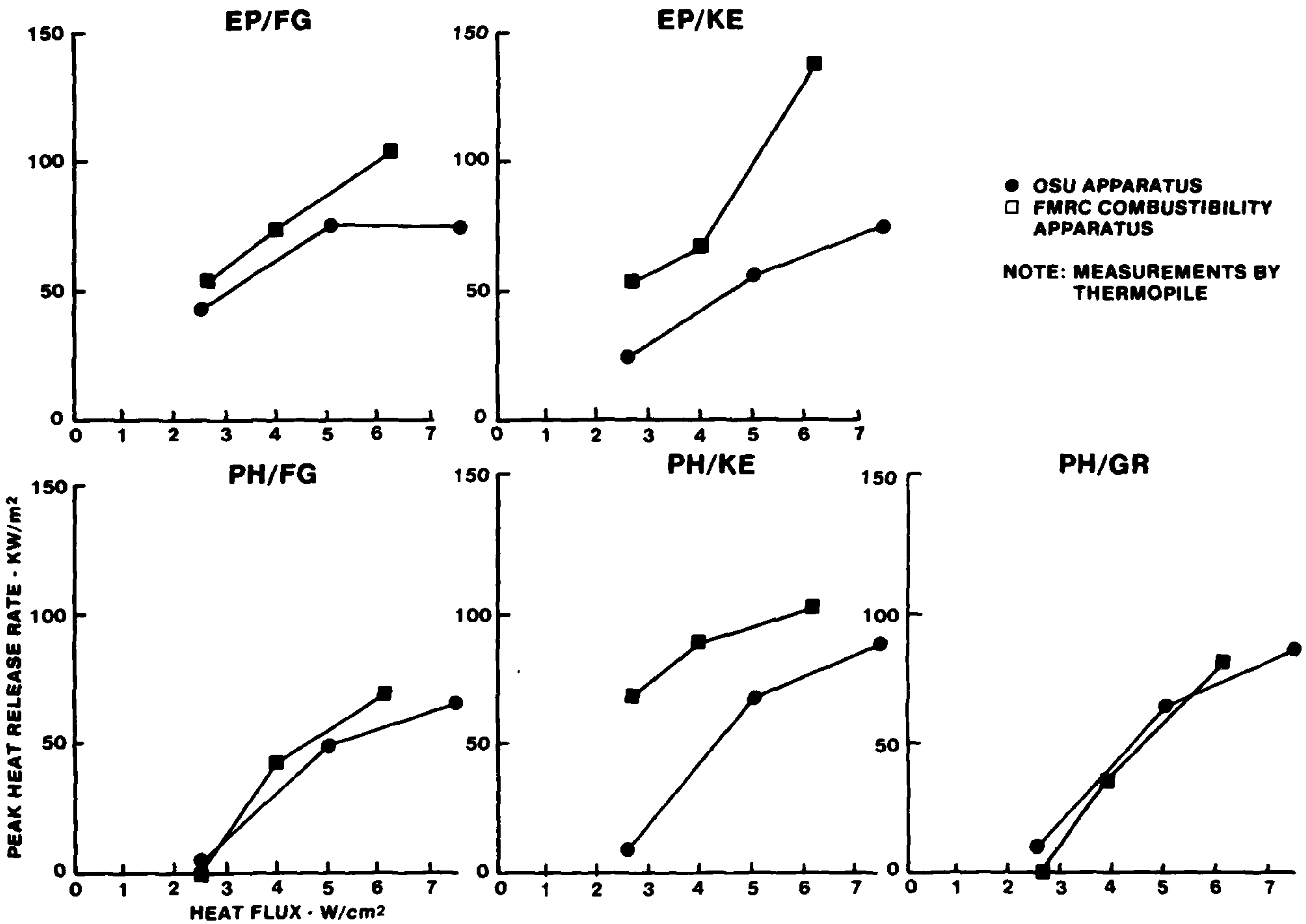

FIGURE 21. COMPARISON OF PEAK HEAT RELEASE RATE BY THERMOPILE MEASUREMENT IN THE OSU AND COMBUSTIBILITY APPARATUSES

vertical wall). For the "creeping" flame spread case, a lateral flame spread device has been developed which, when combined with a theoretical model, provides data for the prediction of flame spread as a function of incident heat flux and time for a given material (reference 14). By contrast, the development of a test methodology for upward flame spread is in an early stage, and consists at this time of a device for measurement of wall flame heat transfer (reference 15). The following is a brief description of results obtained on the five aircraft panels with the above flame spread devices. A more detailed description and analysis of the results are contained in reference 13.

With the lateral flame-spread device, the ignition data is of greatest interest since the low lateral flame spread velocities are probably not as relevant to a rapidly propagating postcrash cabin fire. A minimum heat flux for ignition is experimentally determined as the limit at which no ignition occurs. The minimum heat flux for ignition (W/cm^2) for the panels was as follows (reference 13):

Material	Heat Flux (W/cm^2)
EP/FG	2.03
PH/FG	3.60
EP/KE	2.30
PH/KE	3.40
PH/GR	3.60

Basically, the epoxy panels ignited at a heat flux as low as about 2 W/cm^2 compared to 3.4 - 3.6 W/cm^2 for the phenolic panels. This data is consistent with the early measurement of temperature rise in the 1/4-scale model for the epoxy panels, and the heat release data at 2.5 W/cm^2 in the cone calorimeter and OSU apparatus. However, ignition considerations alone would not predict the poor performance of the phenolic/Kevlar panel measured in the 1/4-scale model. Also, at incident heat flux levels characteristic of an intense cabin fire (e.g., 5 W/cm^2), ignition times for the five panels (vertical orientation) differ by only several seconds or less (reference 13). Thus, it appears that ignition may be an important consideration for some scenarios, provided that heat release rate is also taken into account.

As indicated earlier, the development of a predictive methodology for upward flame spread is far from complete; however, initial test results on the five panels do seem to follow some of the trends exhibited by the other test devices described earlier. For example, the terms t_f and t_b are defined as the time for spread over the flame heat transfer region and the time duration of pyrolysis, respectively. The smaller the dimensionless ratio t_f/t_b is, the greater the propensity for upward flame spread. Data taken at an incident heat flux of 3.7 or 3.8 W/cm^2 indicated the following values for t_f/t_b:

Material	t_f/t_b
EP/FG	12
PH/FG	13
EP/KE	1.3
PH/KE	0.5
PH/GR	18

Thus, these early results do predict the higher flammability of the Kevlar-faced panels in the 1/4-scale model, but do not predict the relative results for epoxy/fiberglass (versus phenolic/fiberglass).

SUMMARY OF RESULTS

Five aircraft-type interior panels were fire tested in a 1/4-scale model and a number of small-scale flammability tests. The following is a summary of the major results:

(1) The greatest increase in air temperature was measured with the epoxy/fiberglass and phenolic/Kevlar panels, in the 1/4-scale model.

(2) Model air temperatures coincided with results obtained with a non-combustible material, for the phenolic/fiberglass and phenolic/graphite panels.

(3) The epoxy/fiberglass panel exhibited the earliest increase in air temperature in the 1/4-scale model; by contrast, the air temperature rise for the phenolic/Kevlar panel was later in time but more sustained.

(4) In the vertical Bunsen burner test method, all five panels were "self-extinguishing" and the phenolic-faced panels exhibited shorter burn lengths than the epoxy-faced panels.

(5) The limiting oxygen test method results indicated that none of the panels would ignite in air (21 percent O_2) when subjected to a small ignition source.

(6) On the basis of flame spread index (I_s), the radiant panel test results indicated that the epoxy-faced panels were generally more flammable than the phenolic-faced panels.

(7) In the OSU apparatus, the phenolic/fiberglass panel had the best ranking (lowest heat release) of the five panels tested at 11 of the 12 conditions.

(8) Total heat release measured in the OSU apparatus increased monotonically with increasing incident heat flux for all materials tested and for both the thermopile and oxygen depletion measurement techniques.

(9) Ignition results obtained in the lateral flame spread device indicated that the epoxy-faced panels ignited at a heat flux as low as 2 W/cm^2 as compared to 3.4 - 3.5 W/cm^2 for the phenolic-faced panels.

(10) Heat release data obtained with the OSU apparatus was consistently lower than similar data obtained with the cone calorimeter and combustibility apparatus.

CONCLUSIONS

An analysis of fire test results obtained in a 1/4-scale model and with small-scale test methods for five aircraft-type interior panels yields the following major conclusions:

(1) On a preliminary basis, an improved fire test method for interior panels is the OSU apparatus operated at 5 W/cm^2, piloted, with measurement of peak heat release rate by oxygen depletion.

(2) Neither the vertical Bunsen burner, limiting oxygen index or radiant panel standardized small-scale test methods correctly predicted the rank order of interior panels determined by the 1/4-scale model; however, of these three test methods, the agreement between model and small-scale results was best with the radiant panel.

(3) Of the three exposure conditions used in the OSU apparatus, 2.5, 5.0, and 7.5 W/cm^2, the mid-heating condition (5.0 W/cm^2) is most appropriate for evaluating the overall fire performance of interior panels in a 1/4-scale model.

(4) Rank ordering of materials fire performance with the OSU apparatus is dependent on incident heat flux, data output (peak versus total heat release), measurement technique (thermopile versus oxygen depletion) and usage of pilot flames.

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